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LIF WASTE CHARACTERIZATION FOR HANDLING/DISPOSAL - 1986

Report No 87-146-K

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ABSTRACT

To facilitate safe handling and disposal of solid waste resulting from limestone injection into the furnace (LIF), detailed chemical and physical solid waste characterization from station and pilot-scale tests has been carried out. "Worst case" (highest CaO content) waste samples were examined before and after fixation by water addition. The highest CaO contents in the wastes (400 g/kg) were associated with the maximum Ca/S ratio (4.0) of sorbent injection. Exothermicity was about $^{v}H^{d}$ -100 cal/g whether limestone or slaked lime was injected. Bulk exothermicity tests gave internal slaking temperatures of about 160-190°C with either sorbent, accompanied by significant expansion. In terms of permeability and shear strength, the fixated wastes resembled regular fly ash and certain earth materials. The wastes were subjected to standard MOE leaching tests, both "as received" and after fixation. LIF wastes were found to be non-'leachate toxic', and essentially suitable for use as landfill or backfill. Recommendations are made for future work.

job	file	date	report no.
31-202-490	837.2412	August 7, 1987	87-146-K

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EXECUTIVE SUMMARY

LIF WASTE CHARACTERIZATION FOR HANDLING/ DISPOSAL - 1986

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Extended testing of direct limestone injection into the furnace (LIF) for acid gas control is scheduled to be held at Lakeview TGS in July/August 1987. To generate useful design data for improved handling/disposal of wastes from the furnace sorbent injection process, detailed waste characterization has been carried out on selected "worst case" (highest CaO) wastes from two previous trials at Lakeview TGS, and on two wastes derived from pilot-scale tests at the Combustion Research Facility, Research Division. The samples were examined in terms of principal chemical and physical properties, before and after fixation by water addition. The highest solid waste CaO contents (~400 g/kg) were associated with the highest rates of sorbent injection (Ca/S ratio ~4.0). Exothermicity was about $\Delta H \approx -100$ cal/g whether limestone or slaked lime was injected. Likewise, bulk exothermicity tests gave internal slaking temperatures of about 160-190°C with either sorbent, accompanied by significant expansion. In terms of engineering characteristics (eg permeability, shear strength) the fixated wastes resembled regular fly ash and certain earth materials. The wastes were subjected to standard MOE leachate extraction tests both "as received" and after fixation. LIF wastes were found to be essentially non-hazardous (ie, non-'leachate toxic') and suitable for use as landfill or backfill. Based on the experimental results, recommendations are made for future work.

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To Dr. W.R. Effer
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Design & Development Division

LIF WASTE CHARACTERIZATION FOR HANDLING/ DISPOSAL - 1986

Ontario Hydro is in the process of evaluating acid gas emission control by direct injection of pulverized limestone into the furnace (LIF). It is also planned to study the effectiveness of using slaked lime and other alternative dry sorbents. Special attention is given to characterization of high-CaO solid wastes, which can pose handling/disposal problems.

1. PREVIOUS WORK

A sample of Consol limestone injection waste was obtained early in 1985 from the Dupont Inc nylon production plant at Martinsville, Virginia, USA. At that time, Consol waste was considered to be the best available substitute for LIF waste expected to be produced during planned tests of limestone injection technology at Lakeview TGS in December, 1985. Accordingly, the Consol waste was characterized in detail, both chemically and physically/1/.

Preliminary characterization of Consol LIF waste showed that it contained by weight about 33.3% of free CaO, <3% of $Ca(OH)_2$, 18.2% of $CaSO_4$, 8% of $CaCO_3$ and 12.5% of unburnt carbon. The material reacted exochemically with water: maximum temperatures of ~100°C were observed by calorimetry, and ~160°C under bulk slaking conditions. The heat of reaction was about -68.9 cal/g, attributed predominantly to hydration of the CaO. Bulk slaking was accompanied by about 15% linear expansion. Based on MOE leachate extraction test results, the 'as received' Consol waste was found to be non-hazardous, ie, non-leachate toxic (Regulation 309 co-disposal test/2/). The 'as received' material on leaching with plain, deionized water (monofill tests) was found suitable for backfill/3/ except for marginally excessive levels of barium, boron and of TDS. Particle size reduction took place on slaking.

Twenty four to forty eight hours after mixing with water, the slaked Consol LIF waste set to a friable plaster-like solid, the consistency of which depended on the proportion of water added. Up to about 75% w/w of added water (dry solids basis), the fresh mix varied from dry to lumpy-moist to a wet plaster-like consistency. Above 75% w/w of added water, phase separation occurred, producing a supernatant aqueous layer. The region around 75% w/w of added water (dry weight basis) appeared to be optimal for handling/disposal purposes. Based on standard MOE leaching tests, the fixated waste was found to be non-hazardous (Regulation 309 co-disposal test), and suitable for backfill (monofill test) except for slightly elevated TDS - attributed to dissolved $CaSO_4$ and $Ca(OH)_2$, contributors of calcium hardness in water.

Engineering/physical tests of Consol waste samples fixated by curing after addition of water indicated that the products resembled natural earth materials.

The following properties of the wastes were measured: --

(a) flow characteristics (an indicator of 'pumpability', found to be enhanced when regular fly ash was added)

(b) bulk density (found to be 1540 to 1580 kg/m^3)

and

(c) water content (found to be 53-64% w/w, dry basis).

The laboratory-cured Consol waste/water mixes (100% relative humidity, 20°C) were examined for: --

(a) shear strength (found to be ~320 kPa after 15 days, resembling glacial till, or K-crete).

(b) consolidation (pre-consolidation pressures found to be 580-1300 kPa, resembling clay soils)

and

(c) permeability (found to be of the order of 10^{-7} cm/s to 10^{-6} cm/s, resembling clays or glacial till).

Since dusting was recognized to be a potential problem during handling/disposal of LIF waste, and it was uncertain whether equipment (ie dustless unloaders) already available on-site at Lakeview TGS and other stations would provide safe, effective

means of adding water, small-scale tests of slaking equipment and of pelletizing equipment were performed. Of the two, conventional slaking equipment was reported to be unpromising. A sample of Consol LIF waste was sent to Ferro-Tech, Wyandotte, Michigan, USA and treated at their pilot-scale facility. The pelletized product was dust-free and gave negligible temperature rise on wetting with water. Ferro-Tech are represented in Canada by the Steve Placek Company Ltd, Toronto, Ontario.

2.0 WORK PROGRAM TO DECEMBER, 1986

After the preliminary characterization work was done on Consol LIF waste, 70 samples of LIF waste samples, originating within Ontario Hydro were obtained, and a number of these characterized in detail both chemically and physically. The sources of these additional samples were as follows:

- Lakeview TGS, December, 1985. Station trials (9 samples).
- Lakeview TGS, June/July, 1986. Station trials (59 samples).
- Combustion Research Facility (CRF), Chemical Research Dept (2 samples).

Since only very small amounts of waste were available from each of the individual CRF tests, the samples received for examination were made into composites taken from different tests under identical sorbent injection conditions.

Identification of the samples of maximum interest and the conditions under which they were sampled are given in Tables 1, 2 and 3 respectively.

3.0 WASTE CHARACTERIZATION

3.1 Chemical Analysis

All 70 of the Ontario Hydro LIF waste samples received were analyzed for free CaO and for $Ca(OH)_2$. The results are given in Table 4. Due to the large number of samples obtained from the June/July, 1986 LIF trial at Lakeview TGS, only those with the highest free CaO contents were selected for more extensive examination, since it was anticipated that these would represent the most problematic wastes in terms of handling/disposal. Major chemical analysis of the selected LIF wastes was extended to include $CaCO_3$, $CaSO_4$ and unburnt carbon. The samples chosen for detailed characterization included LIF wastes from both limestone injection tests and slaked lime injection tests.

TABLE 1

IDENTIFICATION OF LIF WASTE SAMPLES FROM LAKEVIEW TGS
LIF TESTS IN DECEMBER 1985

Sample No	Date	Test No	Sample Time (EST)	Source Hoppers Nos	Side	Sorbent Injection Rate (Mg/h)		Load (MW)	SO_2 (mg/L)	CaO Content Of LIF Waste Sample (g/kg)
						Lime-stone	$Ca(OH)_2$			
1	Dec 10	3	15:45	14	B	13	0	222	877	240
2	Dec 10	3	16:00	11	A	13	0	222	877	340
3	Dec 11	5	13:00	11	A	12.1	0	220	842	340
4	Dec 11	5	13:00	11	A	12.1	0	220	842	360
5	Dec 12	8	13:00	14	B	10.2	0	219	866	290
6	Dec 12	8	13:00	11	A	10.2	0	219	866	310
7	Dec 13	13	15:15	11	A	0	2.6	218	973	120
8	Dec 16	-	-	Truck	#125	-	-	-	-	74
9	Dec 16	-	-	Truck	#126	-	-	-	-	60

Samples Nos 8 and 9 were taken from trucks after water addition had been made using dustless unloader (slaking still incomplete).

TABLE 2

IDENTIFICATION OF LIF WASTE SAMPLES AND TESTING CONDITIONS AT LAKEVIEW TGS IN JUNE/JULY, 1986

Date (1986)	Test No	Load (MW)	SO_2 (ppm)	Sorbent Injected: Lime-stone (Mg/h)	Sorbent Injected: $Ca(OH)_2$ (Mg/h)	West Side Sample No	CaO Content of West Side Sample (g/kg)	East Side Sample No	CaO Content of East Side Sample (g/kg)
Jun 25	1	300	1523	0	0	58	28.6	59	29.7
	2	"	1017	20.8	0	37	338	38	284
Jun 26	3	"	1515	0	0	30	32.0	28	35.7
	4	"	1041	20.5	0	31	298	32	299
	5	"	975	21.0	0	55	318	57	341
Jun 27	6	"	1531	0	0	56	110	54	135
	7	"	1081	18.3	0				
	8	"	1074	16.4	0	47	359	29	222
Jul 2	1	300	1502	0	0	50	24.7	52	7.8
	2	"	1021	16.4	0	49	282	45	183
Jul 3	3	"	1490	0	0	53	8.5	51	8.6
Jul 4	4	"	1014	15.1	0	20	100	48	284
	5	"	1010	17.8	0	19	382	46	363
Jul 7	1	300	1298	0	0	7	46.2	10	42.5
	2	"	955	17.5	0	6	195	9	169
	3	"	828	26.2	0	8	280	21	247
	4	"	1188	0	0				
Jul 8	5	"	1412	0	0	12	29.5	43	17.6
	6	"	875	11.8	0	11	279	15	293
	7	"	855	11.8	0	13	284	14	282
	8	"	812	11.8	0				
	9	"	1296	0	0			18	283
Jul 9	10	220	1258	0	0	44	78.4	25	30.4
								27	271
	11	"	756	15.17	0	35	369	34	350
	12	"	710	15.17	0				
	13	"	705	15.17	0				
	14	"	699	15.17	0				
Jul 10	1	300	1246	0	0	23	126	16	96.2
	2	"	894	20	0			33	264
								36	284
	3	"	825	25	0	17	398	22	404
Jul 11	4	220	1244	0	0				
	5	"	818	14.8	0	1	30	24	311
	6	300	682	22	0	26	429		
Jul 14	1	300	1387	0	0	40	168	42	92.5
	2	"	791	0	11				
	3	220	682	0	11				
	4	"	655	0	11	41	342	39	321

Footnote: Sampling problems were encountered, in that the CaO content of the waste did not always reflect the corresponding sorbent injection conditions reported. For instance, the waste sampled on July 8 (Test No. 9) was found to contain 283 g/kg CaO even though the sorbent injection rate was zero during the test. The most obvious explanation is hold-up in the hoppers from previous test(s). There is clearly a need for careful back-end sampling during trials when front-end conditions are being varied.

TABLE 3

IDENTIFICATION OF COMPOSITE LIF WASTE SAMPLES FROM COMBUSTION RESEARCH FACILITY, CHEMICAL RESEARCH DEPARTMENT

LIF Waste Number (Composite sample)	Sorbent Injected	Ca/S ratio	Identification of CRF Samples Combined to make up the Composite Sample	% By Weight of Composite Sample	CaO Content of Composite Sample (g/kg)
CRF-1	Limestone	3.0	LV 06 Aug 19/85 LV 07 Aug 21/85 LV 08 Aug 23/85 LV 14 Sept 19/85	18.0 32.2 41.5 8.3	267*
CRF-2	$Ca(OH)_2$	2.5	LVHL-09 Sept 22/86 LVHL-10 Sept 24/86 LVHL-16 Oct 31/86 LVHL-17 Nov 4/86 LVHL-18 Nov 7/86	14.1 21.3 20.1 23.8 20.7	7.0*

* The CaO content figures were verified by re-analysis.

TABLE 4

MAJOR CHEMICAL ANALYSIS OF LIF WASTES FROM LAKEVIEW TGS (DEC, 1985 AND JUN/JULY, 1986) AND THE COMBUSTION RESEARCH FACILITY (CHEMICAL RESEARCH DEPT)

Sample Number		Free CaO g/kg	$Ca(OH)_2$ g/kg	$CaCO_3$ g/kg	$CaSO_4$ g/kg	Unburnt Carbon g/kg	Sulphur g/kg	Carbonate as CO_3 g/kg	Sulphite as $CaSO_3$ g/kg
D85	1	240 220 260	<30	49.1	112	109			
"	2	330 340 340	<30	48.4	110	85			
"	3	330 340 350	<30	69.1	67	75			
"	4	400 340 350	<30	69.4	121	69			6.15
"	5	270 320	<30	52.5	140	103			
"	6	290 330	<30	54.6	109	83			
"	7	120 130	<30	17.5	94	101			2.10
"	8	74	30	37.5	78	88			
"	9	60	30	36.4	60	87			
J/J86	59	30.4 29.0	<10						
"	58	28.6	<10						
"	57	341	<10						
"	56	110	<10						
"	55	318	<10						
"	54	135	<10						
"	53	9.5	<10						
"	52	7.8	<10						
"	51	8.6	<10						
"	50	24.7	<10						
"	49	282	<10						
"	48	285 283	<10						
"	47	359	<10						
"	46	363	<10	71	61.9	80.6	14.6	42.8	
"	45	183	<10						
"	44	78.4	<10						
"	43	17.6	<10						
"	42	92.5	<10						
"	41	341 342	<10	109	116.4	50.4	27.4	65.1	
"	40	168	<10						
"	39	321	<10	83.4	101.9	65.4	24.0	50.0	

TABLE 4 (cont'd)

MAJOR CHEMICAL ANALYSIS OF LIF WASTES FROM LAKEVIEW TGS (DEC, 1985 AND JUN/JULY, 1986) AND THE COMBUSTION RESEARCH FACILITY (CHEMICAL RESEARCH DEPT)

Sample Number	Free CaO g/kg	$Ca(OH)_2$ g/kg	$CaCO_3$ g/kg	$CaSO_4$ g/kg	Unburnt Carbon g/kg	Sulphur g/kg	Carbonate as CO_3 g/kg	Sulphite as $CaSO_3$ g/kg
" 38	284	<10						
" 37	338	<10						
" 36	284	<10						
" 35	369	<10	14.7	104.3	68.9	24.6	88.4	
" 34	350	<10	140	102.1	68.6	24.0	84.2	
" 33	264	<10						
" 32	299	<10						
" 31	299	<10						
	296							
" 30	32	<10						
" 29	222	<10						
" 28	35.7	<10						
" 27	271	<10						
" 26	429	<10						
" 25	28.7	<10						
	32.1							
" 24	311	<10						
" 23	126	<10						
" 22	404	<10	91.7	70.3	75.9	16.6	55	
" 21	247	<10						
" 20	96.8	10						
	104							
" 19	382	<10	77.4	76.2	67.2	18.0	46.4	
" 18	283	<10						
" 17	398	<10	114	77.5	63.6	18.3	68.3	
" 16	96.2	<10						
" 15	293	<10						
" 14	282	<10						
" 13	288	<10						
	280							
" 12	29.5	<10						
" 11	279	<10						
" 10	42.5	<10						
" 9	169	<10						
" 8	280	<10						
" 7	46.2	<10						
" 6	195	<10						
" 5	43.2	<10						
" 4	293	<10						
" 3	54.6	<10						
" 2	29	<10						
" 1	30	<10						
CRF-1	260	<30	30.5	137	109	32.2	18.2	
	275							
CRF-2	7.0	<10	77.9	199	79.7	46.9	46.7	
							46.6	

In a spot-check of two December, 1985 limestone injection waste samples, sulphite was determined as $CaSO_3$; the results showed that oxidation to sulphate was fairly complete.

The limited amounts of CRF waste samples available precluded extensive testing beyond major chemical analysis.

3.2 Exothermicity Tests

3.2.1 Calorimetry

The heats of reaction of selected LIF wastes on mixing with water were measured using a styrofoam-jacketed nickel calorimeter and stirrer of total water equivalent 10.9 g. The stirrer, which had a rotational speed of 60 rpm, was used for the first 1 min of each run, and then switched off to minimize frictional heat. In each test, 40 g of the solid LIF waste was allowed to react with various amounts of water, and the exothermic reaction temperatures plotted versus time. A copper-constantan thermocouple was used for temperature measurement. A Hewlett-Packard HP-85 microcomputer and a HP-3421A data aquisition/control unit were used for data collection/reduction.

Graphs of temperature rise versus time for various waste-to-water ratios are shown in Figures 1-7.

Calculated heats of reaction/4/ of selected LIF wastes with water are shown in Table 5.

3.2.2 Bulk Exothermicity

Bulk exothermicity tests were carried out on the selected LIF wastes (omitting CRF-1 and CRF-2 due to insufficient sample) to measure the temperatures attainable within a mass of LIF waste exposed to small amounts of water during bulk handling and storage, ie where mechanical mixing action is practically negligible.

About 2 L of each LIF waste was lightly packed into a cylindrical container of rigid styrofoam (internal dia 14.0 cm, height 15.0 cm), fitted with a rigid styrofoam lid. The underside of the lid was equipped with a water distribution coil, made of perforated silicone tubing. Deionized water was pumped from a reservoir via a calibrated Cole-Parmer peristaltic pump at ~3.9 mL/min over the top of the bulk LIF waste, and allowed to percolate down through the material. This application rate corresponds to a rainfall of ~1.63 cm/h which, based on meteorological data, is possible for southern

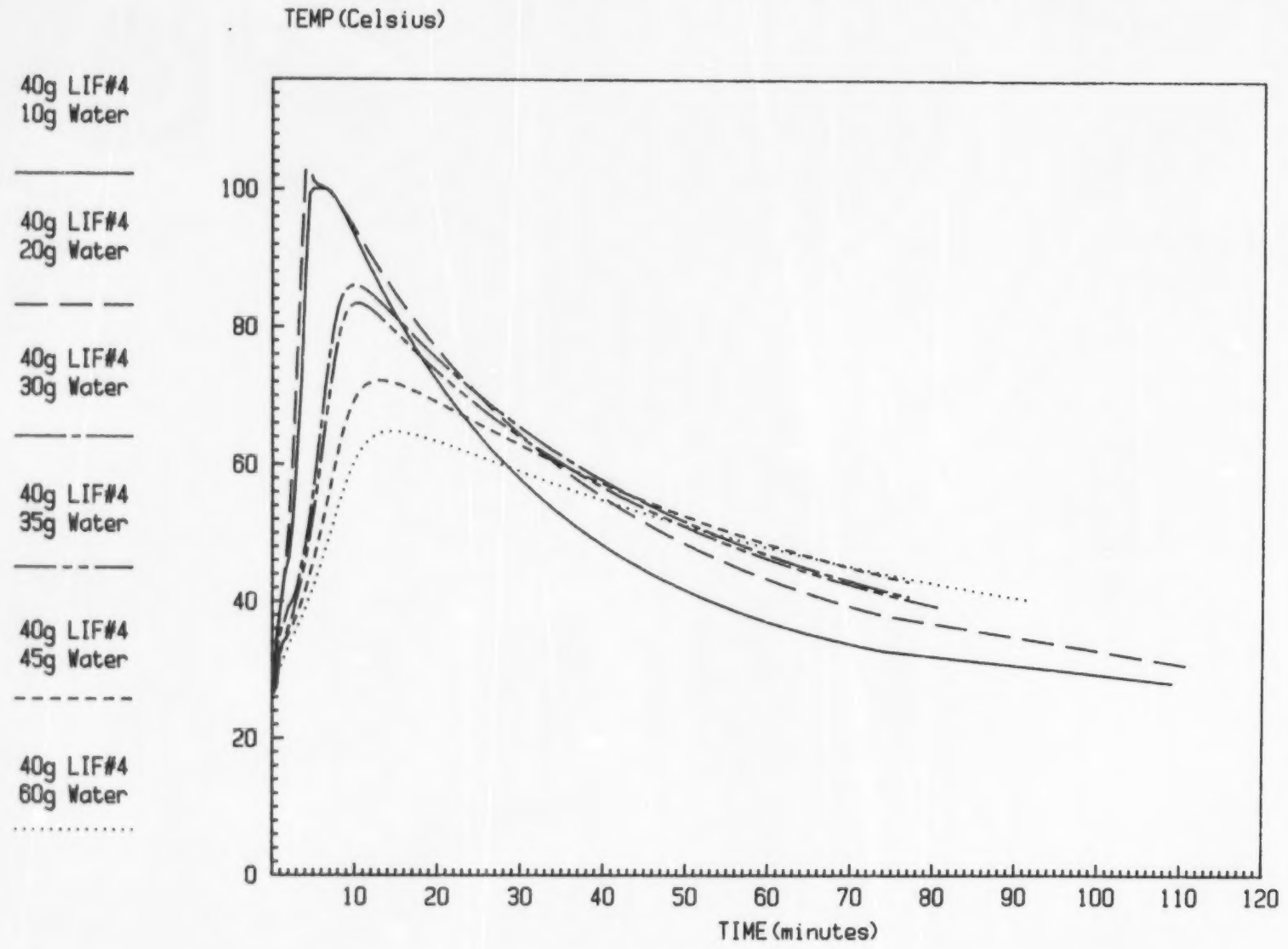
LIF LVTGS Dec, 1985 Sample#4
CALORIMETRY: TEMP(C) VS TIME(min)
TEMP(Celsius)
40g LIF#4
10g Water
40g LIF#4
20g Water
40g LIF#4
30g Water
40g LIF#4
35g Water
40g LIF#4
45g Water
40g LIF#4
60g Water
0
20
40
60
80
100
10
20
30
40
50
60
70
80
90
100
110
120
TIME(minutes)

FIGURE 1

LIF LVTGS Jun/Jul, 1986 Sample#22

CALORIMETRY: TEMP(C) VS TIME(min)

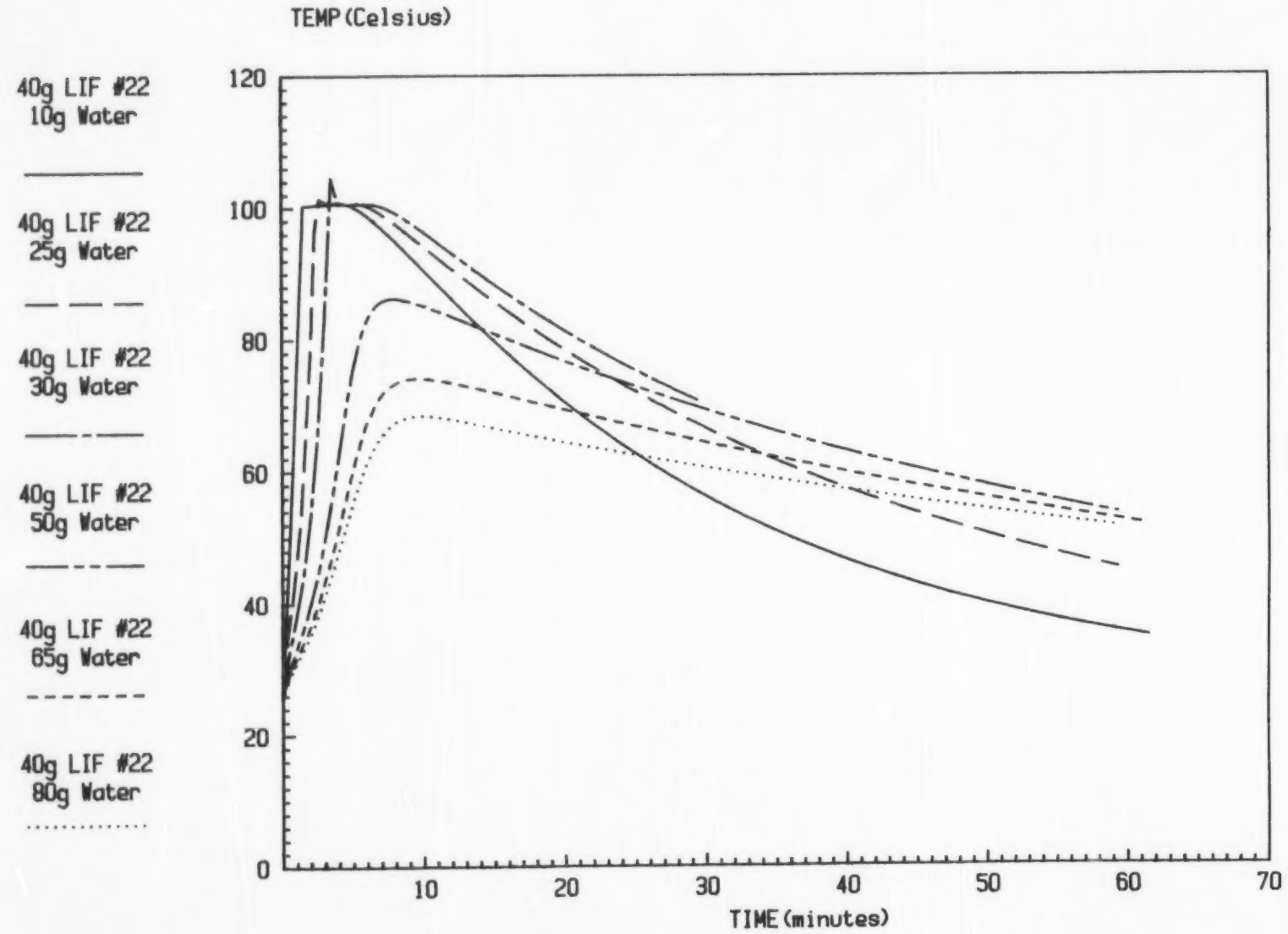

FIGURE 2

LIF LVTGS Jun/Jul, 1986 Sample#35

CALORIMETRY: TEMP(C) VS TIME(min)

40g LIF #35 10g Water	40g LIF #35 25g Water	40g LIF #35 50g Water	40g LIF #35 65g Water	40g LIF #35 80g Water
———	— — —	—·—·—	-------	.....

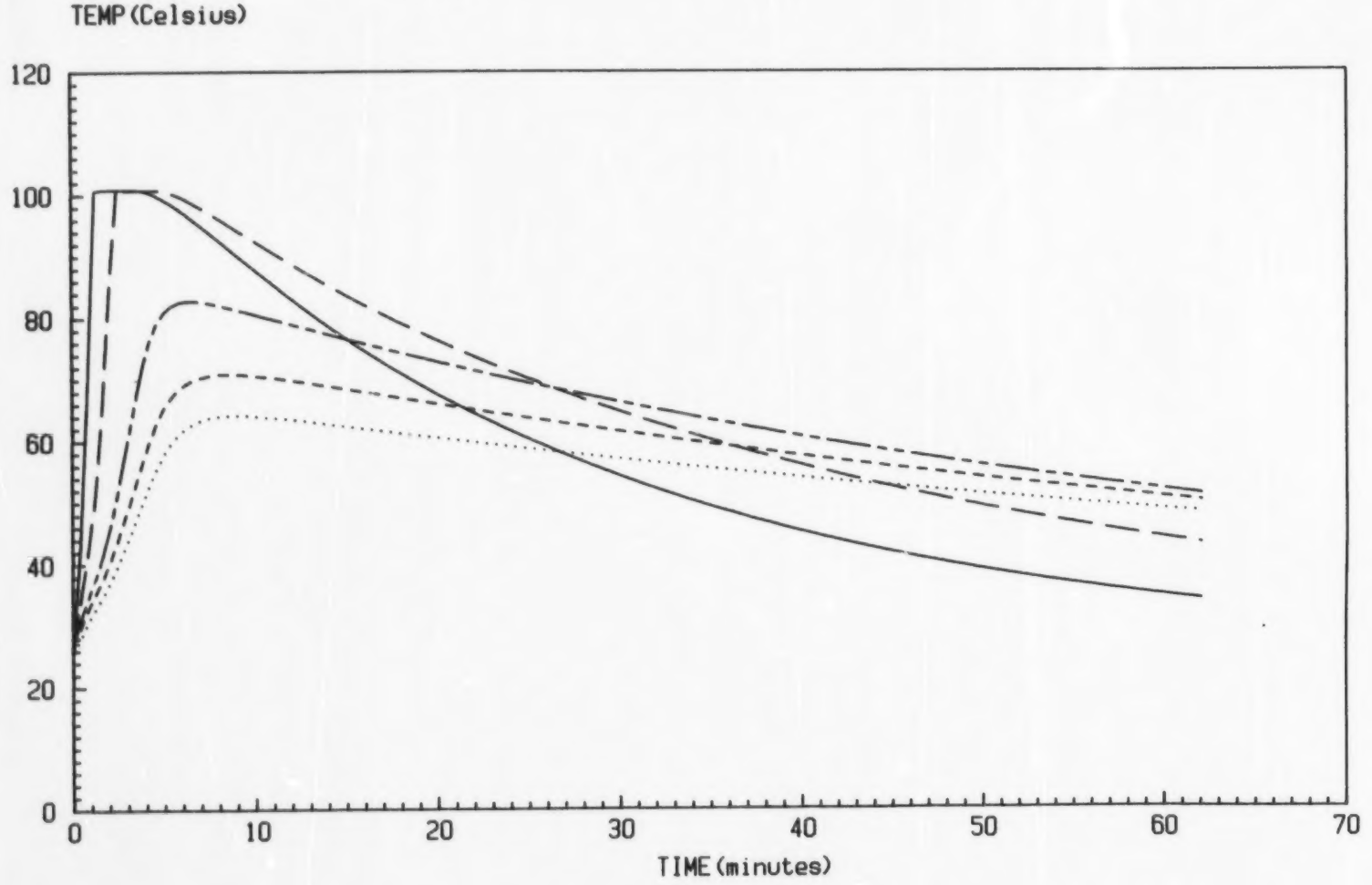

FIGURE 3

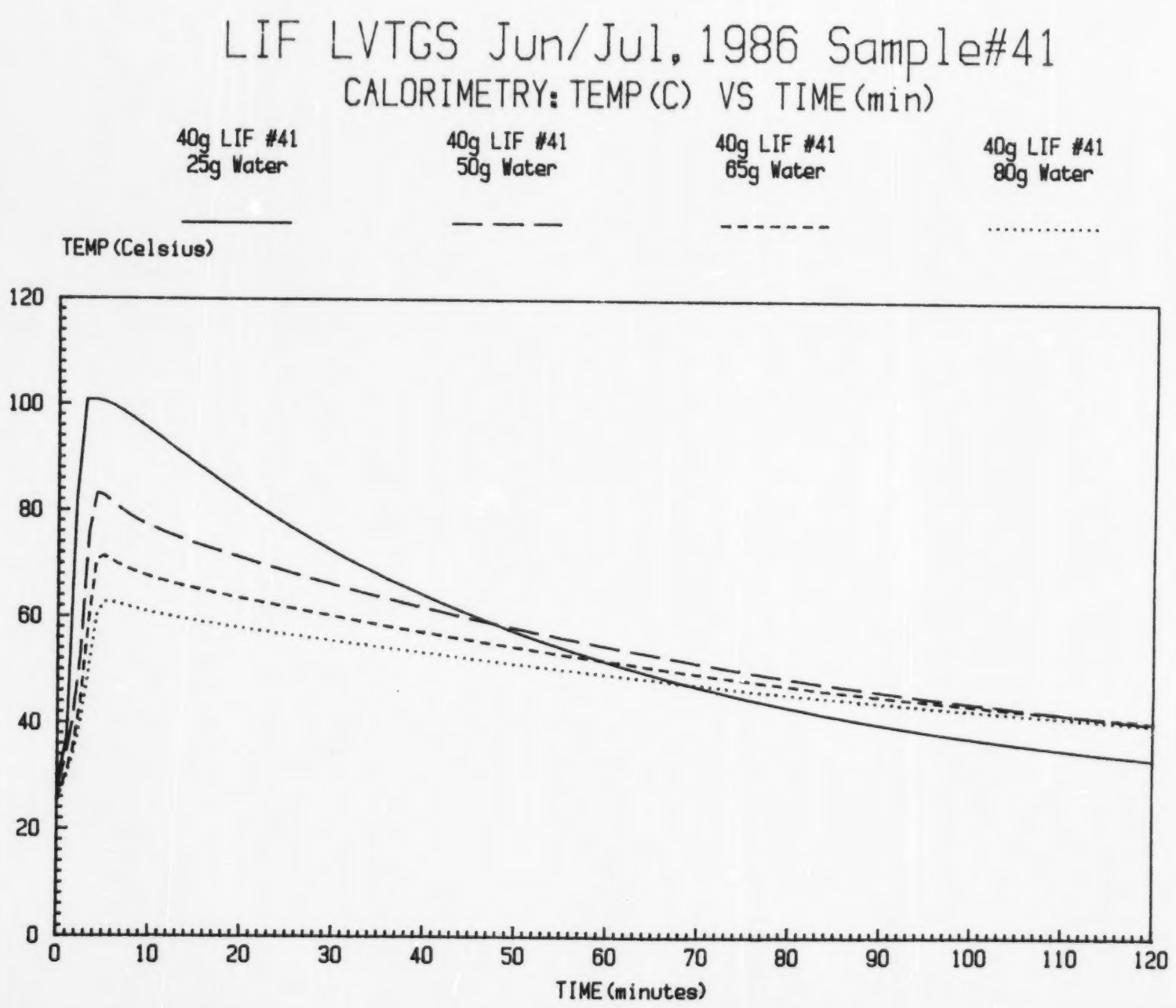
LIF LVTGS Jun/Jul, 1986 Sample#41
CALORIMETRY: TEMP(C) VS TIME(min)
40g LIF #41
25g Water
40g LIF #41
50g Water
40g LIF #41
65g Water
40g LIF #41
80g Water
TEMP(Celsius)
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
TIME(minutes)

FIGURE 4

LIF LVTGS Jun/Jul, 1986 Sample#46

CALORIMETRY: TEMP(C) VS TIME(min)

40g LIF #46 10g Water

40g LIF #46 25g Water

40g LIF #46 50g Water

40g LIF #46 65g Water

40g LIF #46 80g Water

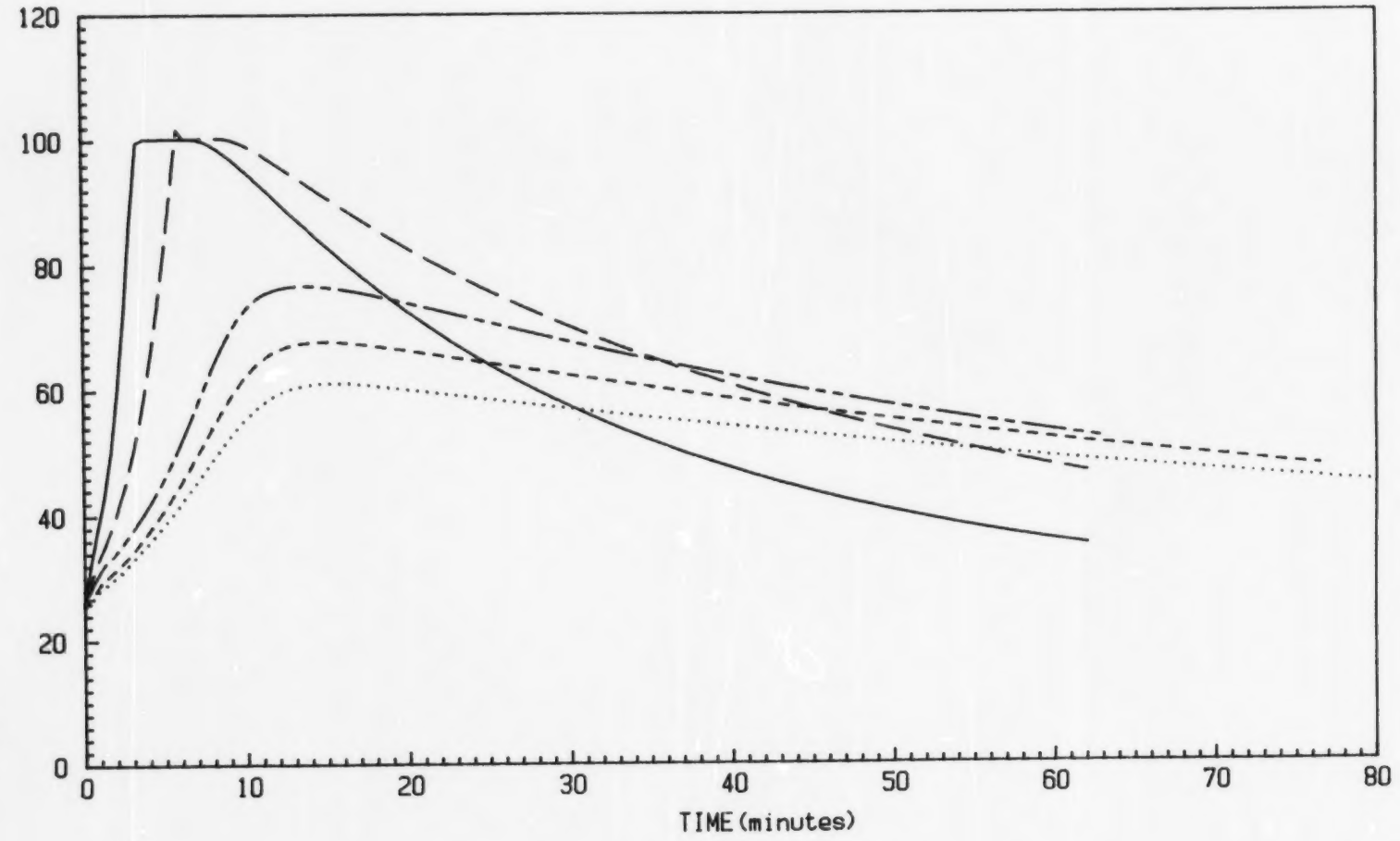

FIGURE 5

LIF-CRF-#1-LV06, 07, 08, 14-Ca/S3.0

CALORIMETRY: TEMP(C) VS TIME(min)

40g CRF-1 15g Water	40g CRF-1 18g Water	40g CRF-1 25g Water	40g CRF-1 40g Water
———	— — —	-------	.....

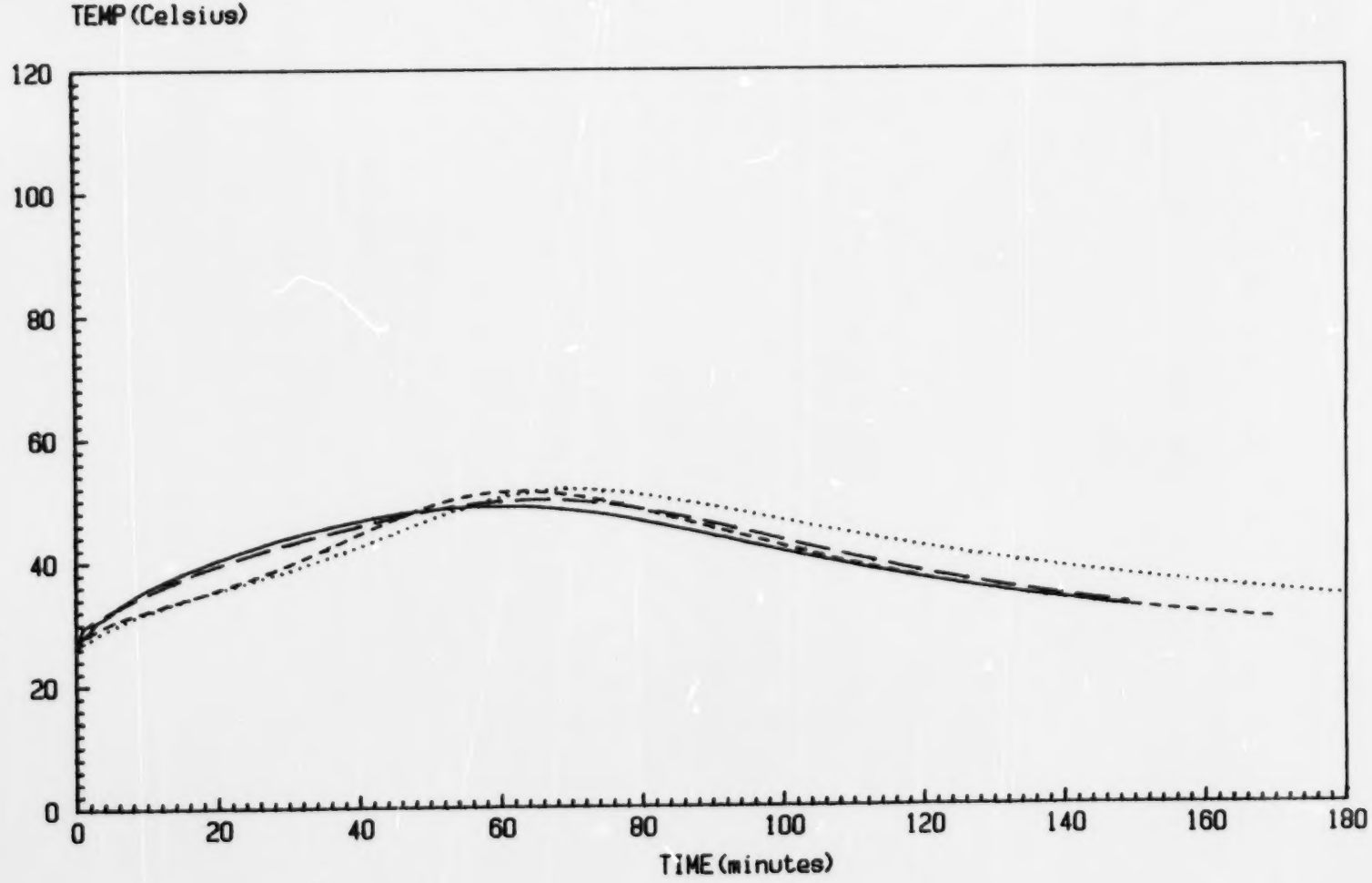

FIGURE 6

LIF-CRF-#2-LVHL-Ca/S 2.5

CALORIMETRY: TEMP(C) VS TIME(min)

40g CRF-2
65g Water

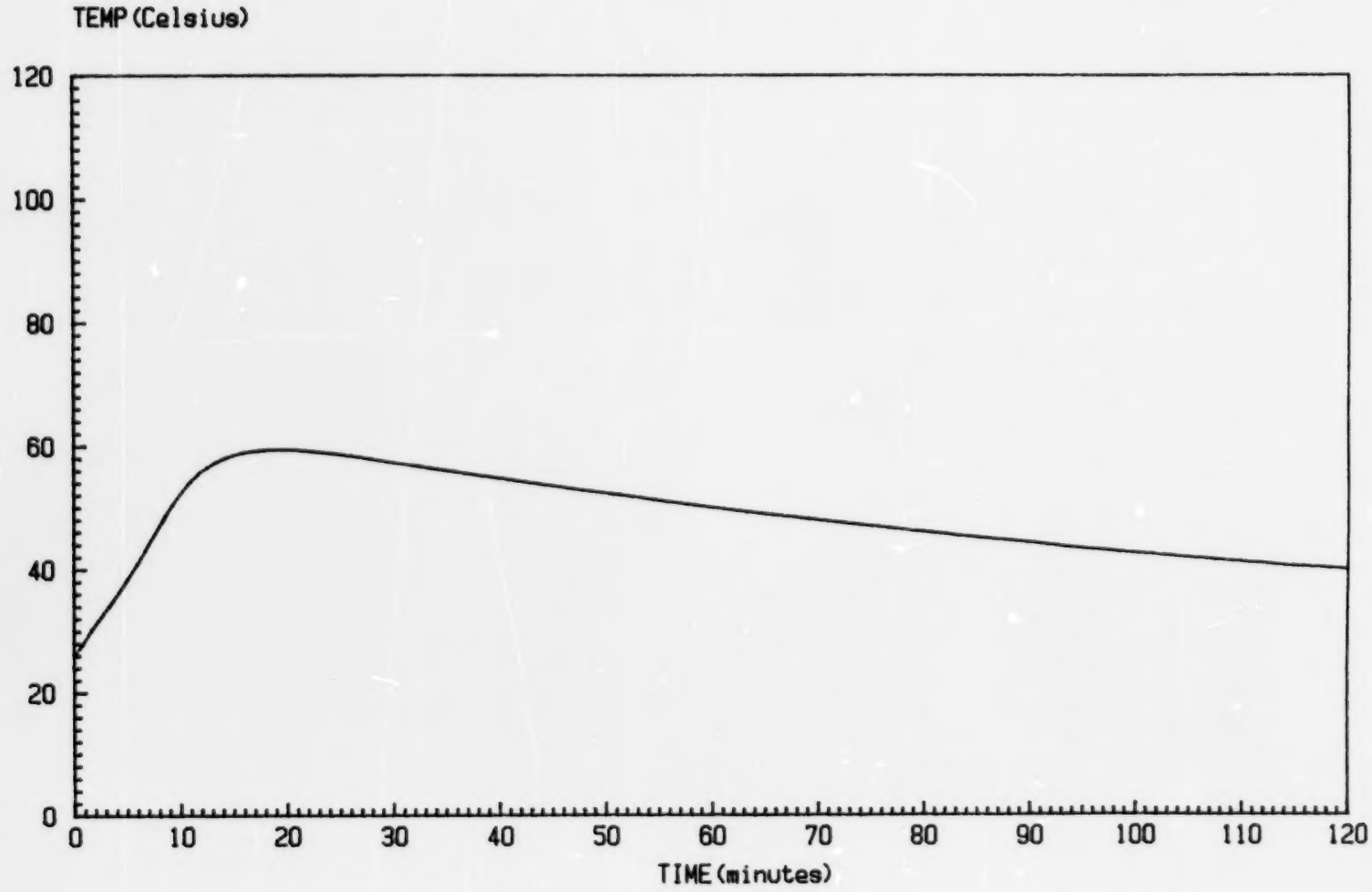

FIGURE 7

TABLE 5

CALCULATED HEATS OF REACTION OF SELECTED LIF WASTES WITH WATER

Water Equivalent of Calorimeter: 10.9 g
40 g of LIF Waste Used for Each Test

LIF Waste Sample	Weight of Water Added to the 40 g LIF Sample (g)	Ambient Air & Water Temperature (°C)	Temperature Projected Back to Time 0 (°C)	ΔH (cal/g)
D85#4 (Limestone sorbent)	10	~23°C	71	-83.3
	20			
	30			
	35			
	45			
	60			
J/J86#22 (Limestone sorbent)	10	~24°C	73	-111.0
	25			
	30			
	50			
	65			
	80			
J/J86#35 (Limestone sorbent)	10	~24°C	68	-100.0
	25			
	50			
	65			
	80			
J/J86#41 (Slaked lime sorbent)	25	~24°C	61	-97.7
	50			
	65			
	80			
J/J86#46 (Limestone sorbent)	10	~24.5°C	65	-93.2
	25			
	50			
	65			
	80			
CRF-1 (Limestone sorbent)	15		65	-52.0
	18			
	25			
	40			
CRF-2 (Slaked lime sorbent)	65	~23°C	66	-79.7

Ontario. Three thermocouple probes were located axially at 10 cm, 7 cm and 4 cm above the base of the container. As the water front passed downward, the rise in temperature at each probe was measured and recorded/1/.

Plots of temperature rise versus time at the three probe locations for each bulk exothermicity test are given in Figures 8 to 13. Steam could be seen issuing from crevices in the surrounding insulation, coincident with the high temperatures recorded.

In each of the bulk exothermicity tests the final, slaked bulk material was found to have expanded. The amount of this expansion, with corresponding test data, are given in Table 6.

3.3 Particle Size Analysis

Particle size distribution measurements were made on the selected LIF wastes in "as received" condition using a HIAC Particle Size Analyzer (Model PC-320).

Particle size distribution was also determined for one of the slaked materials remaining after reacting 40 g of the December, 1985 (D85#4) LIF waste with 10 g of water during the calorimetry tests, since the slaked product was in dry powder form. (The rest of the LIF wastes subjected to calorimetry tests gave lumpy-to-powdery product materials when slaked with small amounts of water, and were clearly unsuitable for particle size analysis).

Results of the particle size analyses are given in Table 7.

3.4 Bulk Density Measurements

Bulk densities of the selected LIF wastes were measured as follows:

Each LIF waste was carefully poured into a 50 mL graduated cylinder up to the 50 mL mark. During transfer, care was taken not to disturb the settling of the waste in the cylinder and to minimize air pockets. The weight of the LIF waste was determined. The cylinder was then tapped with a rod and tamped on the bench top for 5 to 6 minutes. Tamping for this length of time yielded volumes very close to the minimum obtainable by this method.

The results of these bulk density measurements are given in Table 8. For comparison purposes, the bulk density of a sample of regular Lakeview TGS flyash was measured by the same method, and the result is included in Table 8.

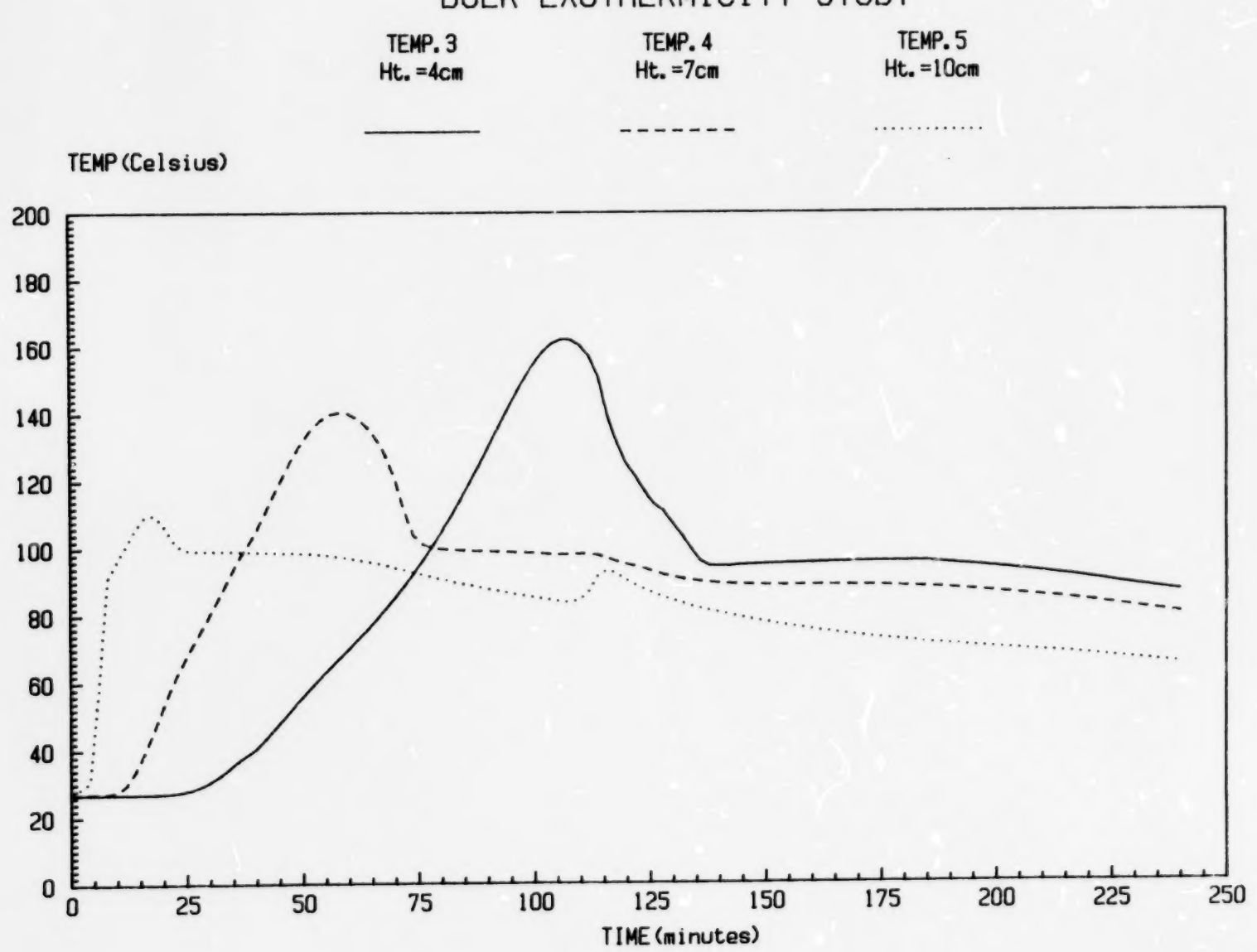
LIF LVTGS Dec, 1985 Sample#4
BULK EXOTHERMICITY STUDY
TEMP. 3
Ht. =4cm
TEMP. 4
Ht. =7cm
TEMP. 5
Ht. =10cm
TEMP(Celsius)
200
180
160
140
120
100
80
60
40
20
0
0
25
50
75
100
125
150
175
200
225
250
TIME(minutes)

FIGURE 8

LIF LVTGS Dec, 1985 Sample#7

BULK EXOTHERMICITY STUDY

TEMP. 3 Ht. =4cm ——————

TEMP. 4 Ht. =7cm - - - - - - -

TEMP. 5 Ht. =10cm .....

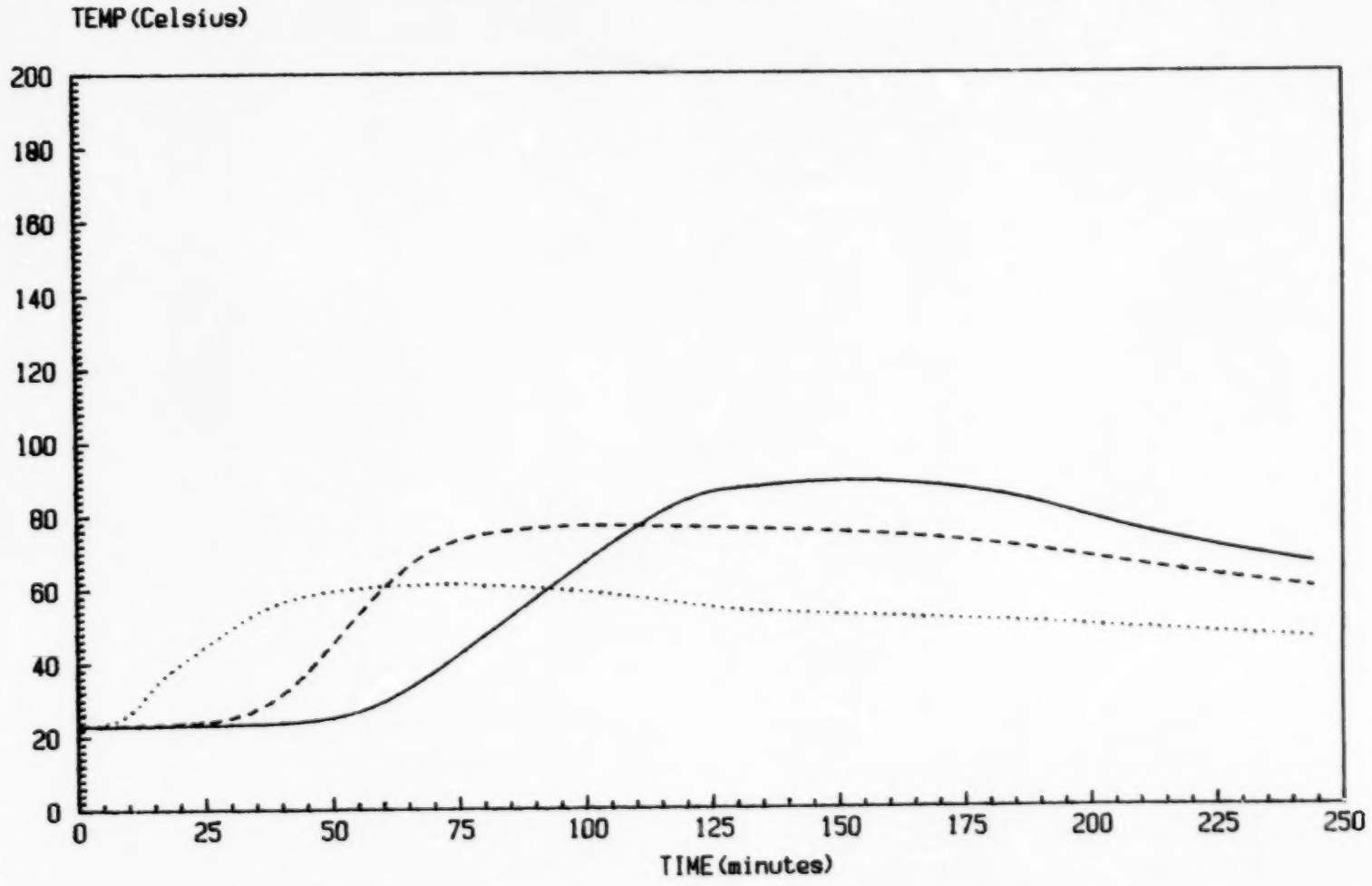

FIGURE 9

LIF LVTGS Jun/Jul, 1986 Sample#22

BULK EXOTHERMICITY STUDY

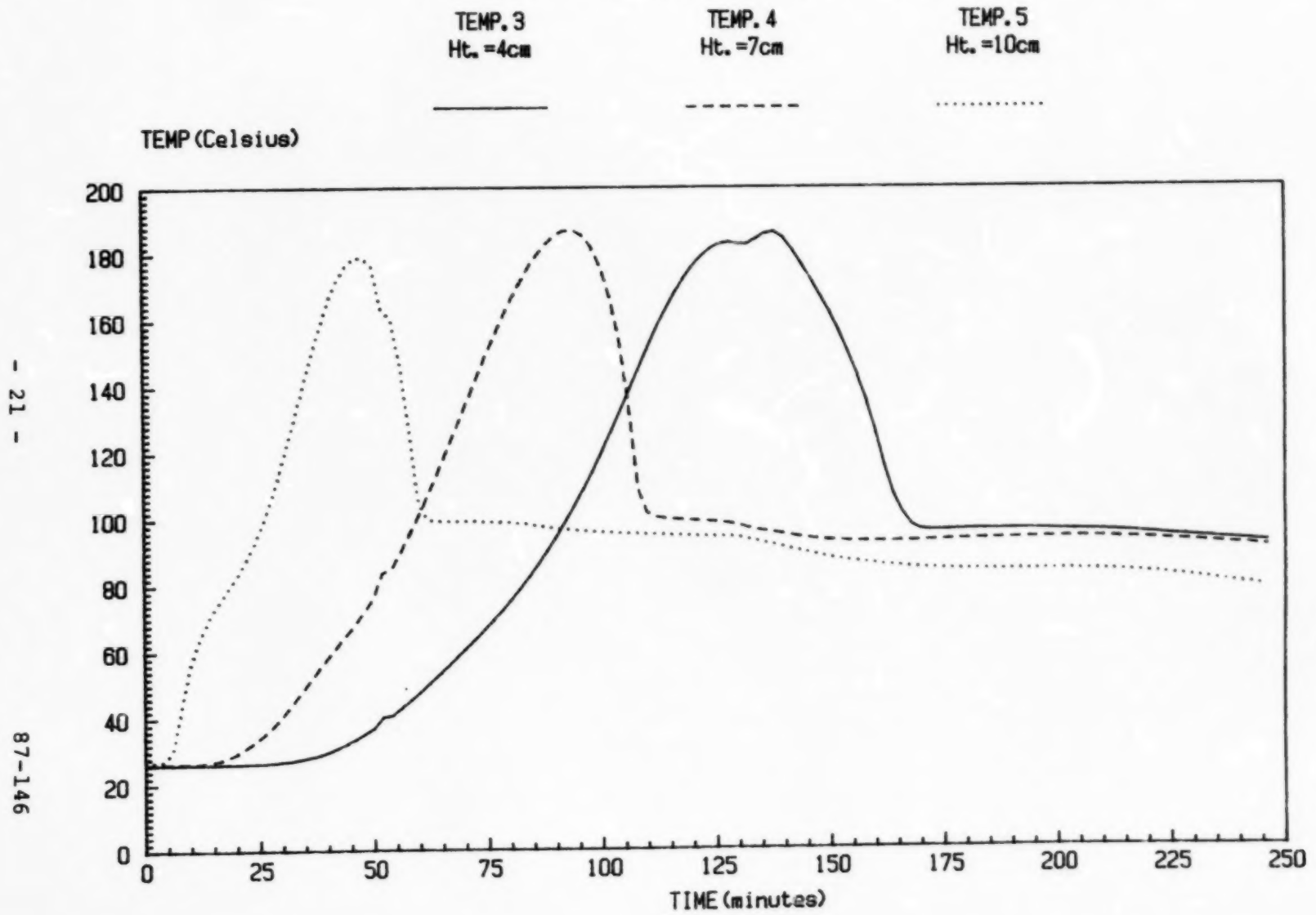

FIGURE 10

LIF LVTGS Jun/Jul, 1986 Sample#35

BULK EXOTHERMICITY STUDY

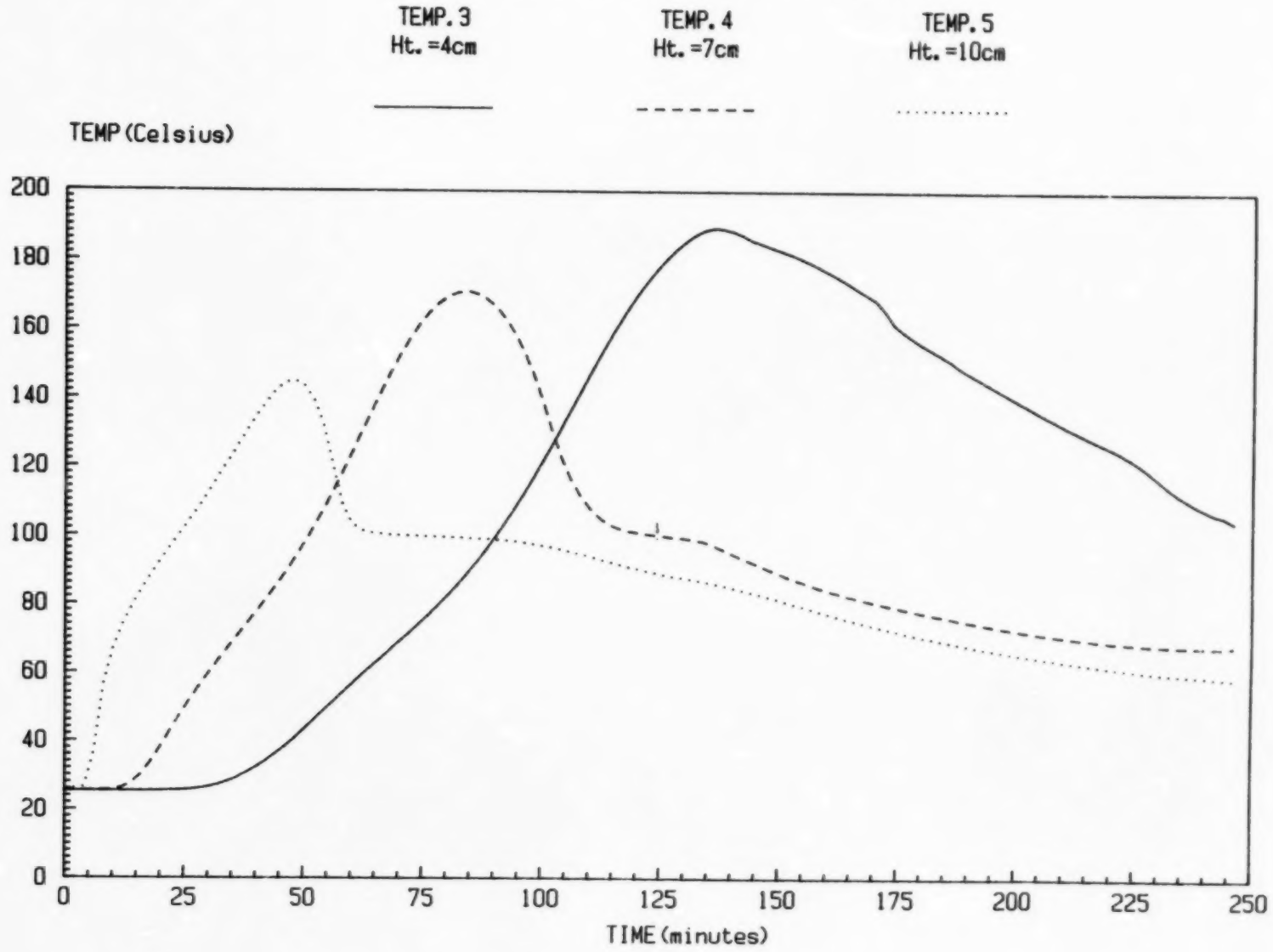

FIGURE 11

LIF LVTGS Jun/Jul, 1986 Sample#41

BULK EXOTHERMICITY STUDY

TEMP. 3 Ht. =4cm

TEMP. 4 Ht. =7cm

TEMP. 5 Ht. =10cm

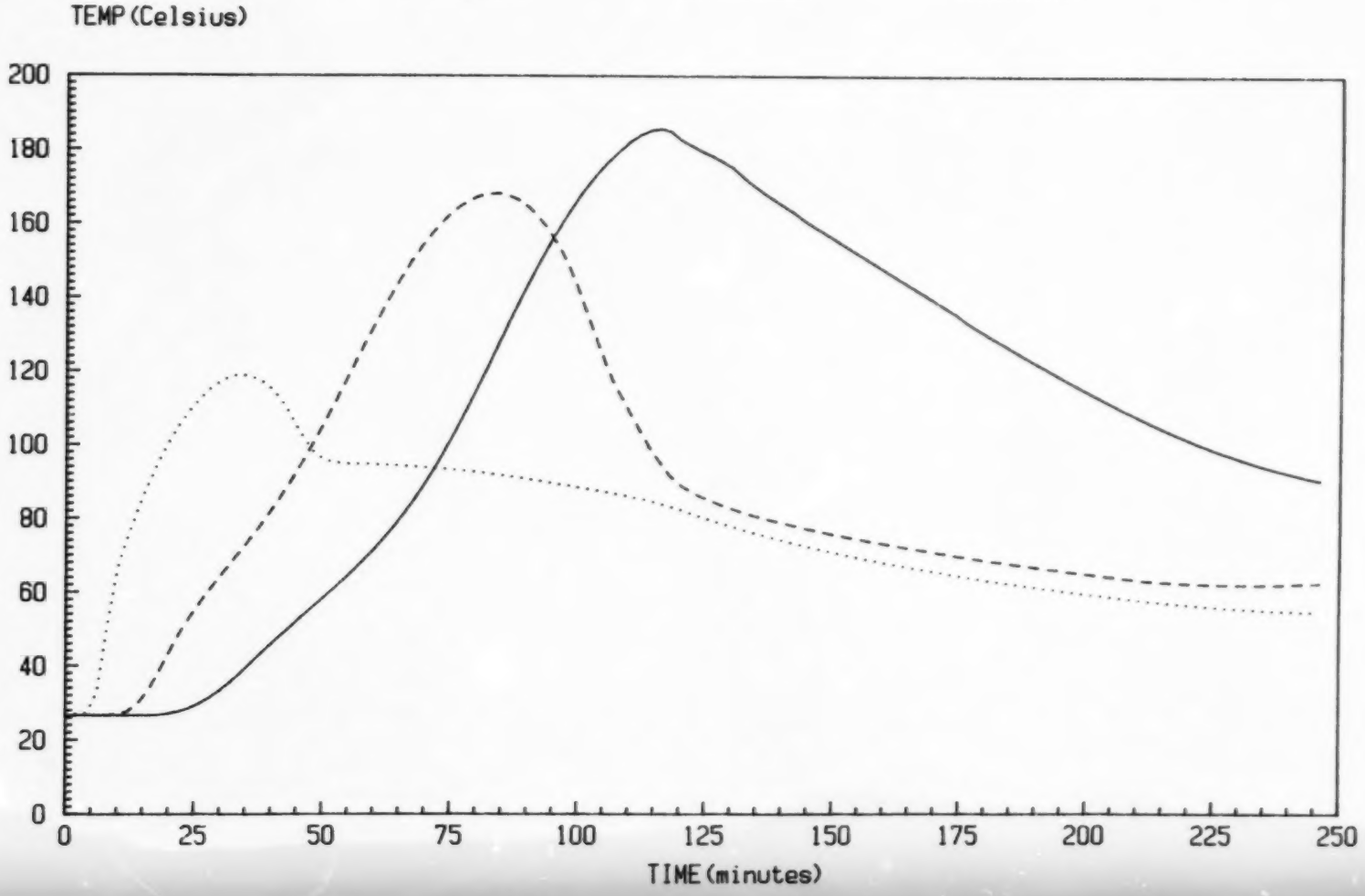

FIGURE 12

LIF LVTGS Jun/Jul, 1986 Sample#46

BULK EXOTHERMICITY STUDY

TEMP. 3 Ht. =4cm ——————

TEMP. 4 Ht. =7cm - - - - - - -

TEMP. 5 Ht. =10cm .....

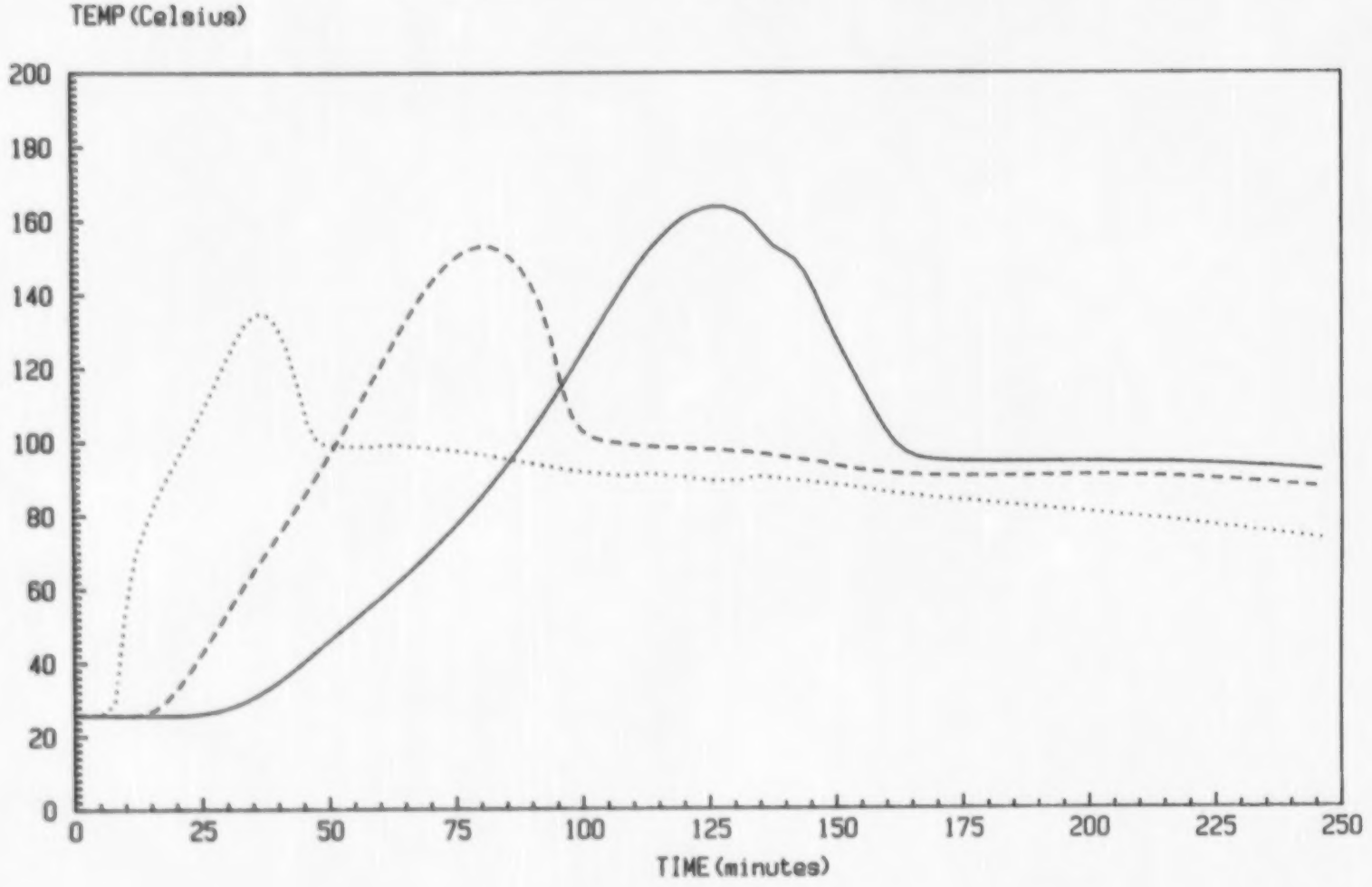

FIGURE 13

TABLE 6

BULK EXOTHERMICITY STUDY OF LIF WASTES: OBSERVATIONS & DATA

LIF Waste Sample	Weight of 2L Of Lightly Packed Waste (kg)	Maximum Temperature Observed (°C) 4 cm level	7 cm level	10 cm level	Volume Expansion (%)	Linear Mid-Diameter Expansion (7 cm level) (%)	CaO Content (g/kg)	Total Time of Test (min)	Total Volume of Water Added (L)	Average Flowrate of Water Added to Waste (mL/min)
D85#4	-	162.2	140.5	110.0	76	30	360	239	0.93	3.9
D85#7	-	88.9	77.1	61.4	-	-	125	245	0.98	4
J/J86 #46	2.37	163.7	152.9	134.8	71	22	363	299	1.16	3.9
J/J86 #35	2.24	189.4	170.8	144.8	53	18	369	303	1.16	3.8
J/J86 #22	2.35	186.5	187.2	179.2	79	25	404	318	1.23	3.9
J/J86 #41	1.54	185.7	168.2	119.0	43	14	341	300	1.14	3.8

TABLE 7

HIAC PARTICLE SIZE ANALYSIS OF LIF WASTES

	Percentage of total no of particles				
Sample Name	5-10 μm	10-25 μm	25-50 μm	50-100 μm	>100 μm
D85#4*	73.23	25.00	1.70	0.12	0.01
D85#4-slaked* 10 gH_2O to 40 g solid	57.20	33.93	7.73	1.06	0.10
J/J86#41	75.9	23.4	0.65	0.05	0.02
J/J86#46	69.2	29.0	1.8	0.01	0
J/J86#35	79.7	19.1	1.1	0.13	0
J/J86#22	71.3	26.8	1.8	0.12	0
CRF-1	77.9	21.1	0.94	0.08	0.04
" -repeat	77.3	21.5	1.1	0.10	0.02
CRF-2	72.49	26.14	1.12	0.23	0
" -repeat	73.46	25.88	0.57	0.09	0

* For D85#4, both the "as received" and slaked LIF waste samples were subjected to particle size determination

TABLE 8

BULK DENSITY MEASUREMENTS OF LIF WASTES

Sample	Bulk Density - Average (g/mL) (number of tests in brackets)		
	Initial	After Tamping for 1 minute	After Tamping for 5 minutes
LVTGS Fresh Hopper Flyash - Sept 23/85	0.69 (4)	0.88 (4)	1.08 (4)
D85#4	0.74 (10)	1.00 (10)	1.13 (10)
J/J86#22	0.80 (2)	1.07 (2)	1.23 (2)
J/J86#35	0.73 (2)	0.97 (2)	1.18 (2)
J/J86#46	0.82 (2)	1.09 (2)	1.19 (2)
J/J86#41	0.51 (2)	0.67 (2)	0.85 (2)
CRF-1	0.43 (1)	0.57 (1)	0.77 (1)
CRF-2	0.35 (1)	0.47 (1)	0.63 (1)

3.5 MOE Leaching Tests

Leaching tests were carried out on the selected LIF wastes "as received". The Ontario MOE Regulation 309 Leachate Extraction Procedure/2/, co-disposal-aerobic method was used.

Analyses of the leachates are reported in Tables 9 and 10 (in Table 10 under the "as received" columns).

Table 9 shows that the "as received" D85#4 LIF sample was subjected to fairly extensive leaching conditions beyond those required by Regulation 309, ie under anaerobic as well as aerobic conditions, both with and without addition of acetic acid for pH adjustment.

The leaching test results given in Table 10 were exclusively obtained following the Regulation 309 Procedure, ie under aerobic conditions and with addition of acetic acid for pH adjustment. Table 10 permits comparison of the Regulation 309 leaching characteristics for LIF wastes "as received", "fixated and cured" and "fixated and dried" (see below).

3.6 LIF Waste Fixation Procedures

The selected LIF wastes were fixated as follows:

A predetermined amount of Toronto tap water was added to 500 g - 700 g of each LIF waste and the products mixed for about 5 min using a Hobart mixer at low speed, to give a wet plaster-like consistency. It was recognized that in disposal practice the material could either be allowed to set slowly by placement in bulk at a designated landfill site, or else set more rapidly by placement in shallow lifts which would accelerate drying and improve local working conditions.

Accordingly, for each LIF waste two tests were done:

(a) The water/LIF waste mixture was poured into a plastic container with a loose-fitting cover, placed in a 100% humidity room at 23°C, and allowed to cure for 7 days. This sample was labelled "Fixated and Cured" (abbreviation: FC).

(b) The water/LIF waste mixture was poured into aluminum trays in shallow (1 to 2.3 cm) layers and allowed to air dry in the open laboratory (24 to 25°C) for 4 days. This sample was labelled "Fixated & Dried" (abbreviation: FD).

TABLE 9

MOE LEACHATE EXTRACTION: ANALYTICAL RESULTS/2,3/*

LAKEVIEW TGS LIF WASTE - DEC 85 SAMPLE #4, "AS RECEIVED" CONDITION

Parameter	Monofill		Co-Disposal		Backfill Use: Maximum Acceptable Extract Concentration (Monofill Test) /1,2,3/	Hazardous Waste Categorization: Maximum Extract Concentration For Exemption /1,2/
	Aerobic	Anaerobic	Aerobic	Anaerobic		
pH	12.2	12.8	12.8	12.8	-	-
Specific Conductivity	900	920	NA	NA	-	-
As	<0.001	<0.001	<0.001	<0.001	0.05	5
Ba	<1	<1	<1	<1	1.0	100
B	4.08	4.00	4.00	3.82	5.0	500
Cd	<0.0001	0.0002	<0.0001	<0.0001	0.005	0.5
Cr (total)†	0.12	0.12	0.13	0.13	0.05	5
'WAD' (CN)	<0.04	<0.04	<0.04	<0.04	0.2	20
F	1.25	1.15	1.60	1.60	2.4	240
Pb	<0.0002	<0.0002	<0.0002	<0.0002	0.05	5
Hg	<0.0002	<0.0002	<0.0002	<0.0002	0.0001	0.1
NO_3 (as N)	0.05	0.05	0.05	0.05	10.0	1000
NO_2 (as N)	0.0003	<0.003	0.003	0.003	1.0	100
Total [NO_3^- + NO_2^-] (as N)	0.05	0.05	0.05	0.05	10.0	1000
U†	<0.01	<0.01	<0.02	<0.02	0.02	2
PCBs	<0.001	<0.001	<0.001	0.0016	0.003	0.3
Ra-226 (pCi/L)	0.85	2.10	9.20	3.10	3.0 pCi/L	300 pCi/L
Se	0.013	0.016	0.018	0.017	0.01	1
Ag	<0.0002	<0.0002	<0.0002	<0.0002	0.05	5
Cl^-	52	52	47	49	1250	-
Cu	0.002	0.003	0.005	0.002	5.0	-
Fe	<0.05	<0.05	<0.05	<0.05	1.5	-
Mn	<0.02	<0.02	<0.02	<0.02	0.25	-
Organic N	0.08	0.08	0.11	0.15	0.75	-
Phenols	<0.001	0.004	0.004	0.006	0.01	-
SO_4	1457	1436	1410	1327	2500	-
TDS	3734	3760	NA	NA	2500	-
TOC	<1	<1	NA	NA	25	-
Zn	<0.02	<0.02	<0.02	<0.02	25	-
Ca	1550	1590	2990	3000	-	-
Mg	0.02	0.02	0.02	0.02	-	-
Na	1.14	1.11	1.08	1.06	-	-
K	2.20	2.20	2.10	2.00	-	-
Br	1.3	1.4	1.2	1.4	-	-
I	0.19	0.21	0.18	0.23	-	-
Ti	<0.5	<0.5	<1	<1	-	-
V	<0.01	<0.01	<0.01	<0.01	-	-
NH_3	<0.01	<0.01	<0.01	<0.01	-	-

† Analytical interference due to high background Ca concentrations
NA Denotes not applicable due to acetic acid addition in co-disposal tests

TABLE 10

MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED" AND FIXATED - REGULATION 309/2/* CO-DISPOSAL - AEROBIC

	D85#4			J/J86#46			J/J86 #19	J/J86#35			
Parameter	As Rec'd	Fixated & Cured	Fixated & Dried	As Rec'd	Fixated & Cured	Fixated & Dried	As Rec'd	As Rec'd	Fixated & Cured	Fixated & Dried	Hazardous Waste Categorization: Maximum Extract Concentration For Exemption (Co-Disposal Test)/2,3/
pH	12.8	12.4	12.3	12.4	12.3	12.4	12.3	12.4	12.3	12.5	-
As	<0.001	0.0014	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	5
Ba	<1	<2	<1	<3	<2	<1	<3	<3	<2	<1	100
B	4.00	0.2	1.1	3.79	0.1	0.9	4.33	4.93	0.2	0.93	500
Cd	<0.0001	<0.0005	<0.0001	<0.0005	<0.0002	<0.0001	<0.0005	<0.0005	<0.0005	<0.0001	0.5
Cr (total)†	0.13	<0.1	<0.1	0.094	<0.1	<0.1	0.110	0.120	<0.1	<0.1	5
'WAD' (CN)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	20
F	1.60	2.2	1.6	2.3	2.2	1.2	2.4	2.9	2.0	1.4	240
Pb	<0.002	<0.010	<0.005	<0.010	<0.002	<0.005	<0.010	<0.010	<0.010	<0.005	5
Hg	<0.0002	0.0002	<0.0002	<0.0002	0.0002	<0.0002	<0.0002	<0.0002	0.0002	0.00095	0.1
NO_3 (as N)	0.05	0.02	0.08	<0.23	0.12	0.06	<0.23	0.23	0.02	0.10	1000
NO_2 (as N)	0.003	0.01	0.02	0.01	0.21	0.01	0.01	0.01	0.01	0.01	100
Total [NO_3^- + NO_2^-] (as N)	0.05	0.03	<0.10	-	0.33	0.07	-	0.24	0.03	0.11	1000
U†	<0.02	<0.04	<0.02	<0.05	<0.02	<0.02	<0.05	<0.05	<0.02	<0.02	2
PCBs	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.3
Ra-226	9.20	3.3	6.2	15	1.7	12	17	12	2.7	15	300 pCi/L
Se	0.018	0.0048	0.008	0.015	0.003	0.009	0.011	0.010	0.0041	0.006	1
Ag	<0.0002	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005	5
Cl^-	47	31	43	33	31	28.3	40	70	53	50	-
Cu	0.005	0.002	<0.1	0.005	<0.05	<0.1	0.002	0.002	0.002	<0.1	-
Fe	<0.05	<0.1	<0.2	<0.05	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	-
Mn	<0.02	<0.05	<0.1	<0.1	<0.05	<0.1	<0.1	<0.1	<0.05	<0.1	-
Organic N	0.11	<0.1	<0.1	0.27	<0.1	<0.1	0.35	0.24	<1	<0.1	-
Phenols	0.004	-	0.008	<0.001	<0.001	0.001	0.001	0.004	0.008	<0.001	-
SO_4^-	1410	1400	1000	1451	667	1400	1482	1533	1000	1140	-
Zn	<0.02	<0.05	<0.05	<0.05	<0.02	<0.05	<0.05	<0.05	<0.05	<0.05	-
NH_3	<0.01	0.03	0.026	-	0.04	0.015	-	-	0.05	0.033	-

* All concentrations given in mg/L except Ra-226, given in pCi/L

† Analytical interference due to high background Ca concentrations

TABLE 10 (cont'd)

MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED" AND FIXATED - REGULATION 309/2/*
CO-DISPOSAL - AEROBIC

Parameter	J/J86 #34	J/J86#22			J/J86 #17	J/J86#41			Hazardous Waste Categorization: Maximum Extract Concentration For Exemption (Co-Disposal Test)/2,3/
	As Rec'd	As Rec'd	Fixated & Cured	Fixated & Dried	As Rec'd	As Rec'd	Fixated & Cured	Fixated & Dried	
pH	12.4	12.4	12.3	12.5	12.4	12.4	12.3	12.3	-
As	<0.001	<0.001	<0.001	<0.001	<0.001	0.0026	<0.001	0.0025	5
Ba	<3	<3	<2	<1	<3	<3	<2	<1	100
B	5.4	3.27	0.1	0.5	3.35	2.75	0.13	0.13	500
Cd	<0.0005	<0.0005	<0.0005	<0.0001	<0.0005	<0.0001	<0.0002	<0.0001	0.5
Cr (total)†	0.120	0.100	<0.1	<0.1	0.095	0.110	<0.1	<0.1	5
'WAD' (CN)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	20
F	1.5	1.1	2.3	1.3	0.8	2.3	3.5	1.7	240
Pb	<0.010	0.010	<0.010	<0.005	<0.010	<0.010	<0.002	<0.005	5
Hg	<0.0002	<0.0002	0.0002	0.00028	<0.0002	<0.0002	0.0003	<0.0002	0.1
NO_3 (as N)	<0.23	<0.23	0.17	<0.07	0.23	<0.23	0.01	0.01	1000
NO_2 (as N)	0.01	0.01	0.30	0.01	0.01	0.02	0.02	<0.003	100
Total [NO_3^- + NO_2^-] (as N)	-	-	0.47	0.08	0.24	-	0.03	-	1000
U†	<0.05	<0.05	<0.04	<0.02	<0.05	<0.05	<0.02	<0.02	2
PCBs	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.3
Ra-226	14	19	3.4	12	15	14	2.3	5.1	300 pCi/L
Se	0.018	0.0048	0.008	0.015	0.003	0.009	0.011	0.010	1
Ag	<0.0002	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	5
Cl^-	60	51	37	44.5	65	54	52	38	-
Cu	0.005	0.005	0.003	<0.1	<0.001	<0.001	<0.05	<0.1	-
Fe	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.05	<0.2	-
Mn	<0.1	<0.1	<0.05	<0.1	<0.1	<0.1	<0.05	<0.1	-
Organic N	0.27	0.24	<0.1	0.14	0.25	0.28	<0.1	<0.1	-
Phenols	0.005	0.004	0.004	<0.001	0.002	0.002	<0.001	0.008	-
SO_4^-	1531	1378	1000	1410	1266	1460	940	1090	-
Zn	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.02	<0.05	-
NH_3	-	-	0.03	0.014	-	-	0.06	0.026	-

* All concentrations given in mg/L except Ra-226, given in pCi/L
† Analytical interference due to high background Ca concentrations

TABLE 10 (cont'd)

MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED" AND FIXATED - REGULATION 309/2/*
CO-DISPOSAL - AEROBIC

Parameter	J/J86 #39	CRF-1		CRF-2		CONSOL**			Hazardous Waste Categorization: Maximum Extract Concentration For Exemption (Co-Disposal Test)/2,3/
	As Rec'd	As Rec'd	Fixated & Cured	As Rec'd	Fixated & Cured	As Rec'd	Fixated & Cured	Fixated & Cured	
pH	12.3	12.4	12.4	12.3	12.2	12.5	12.7	12.4	-
As	<0.001	0.0129	0.0014	0.0021	0.0043	<0.001	<0.001	<0.001	5
Ba	<3	<2	<2	<2	<2	1.1	<1.0	<1.0	100
B	3.54	2.25	0.05	2.0	0.1	5.6	0.40	0.09	500
Cd	<0.0005	<0.0005	<0.0005	<0.0001	<0.0002	<0.0001	<0.0003	<0.0002	0.5
Cr (total)†	0.120	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	0.1	5
'WAD' (CN)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.05	<0.04	<0.04	20
F	2.2	1.7	1.2	1.9	1.3	0.98	1.00	0.9	240
Pb	<0.010	<0.010	<0.010	<0.005	<0.002	<0.002	<0.005	<0.004	5
Hg	<0.0002	0.0007	0.0006	0.0002	<0.0002	<0.0002	0.0005	0.0002	0.1
NO_3 (as N)	<0.23	0.11	0.02	0.24	0.08	0.17	0.031	0.025	1000
NO_2 (as N)	0.01	0.18	0.03	0.14	0.05	0.03	0.019	0.019	100
Total [NO_3^- + NO_2^-] (as N)	-	0.29	0.15	0.38	0.13	0.20	0.050	0.44	1000
U†	<0.05	<0.04	<0.02	<0.02	<0.02	0.03	<0.05	<0.05	2
PCBs	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	<0.0002	<0.001	0.3
Ra-226	12	1.3	1.2	0.5	0.5	0.6	0.3	0.7	300 pCi/L
Se	0.010	0.0163	0.0117	0.0196	0.0091	0.013	<0.001	<0.001	1
Ag	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0002	0.0031	<0.0005	5
Cl^-	49	22	24	90	75	136	154	146	-
Cu	0.002	0.002	<0.1	1	<0.05	0.07	<0.010	<0.002	-
Fe	<0.2	<0.1	<0.1	<0.1	<0.05	<0.5	<0.1	<0.	-
Mn	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
Organic N	0.38	<0.1	<0.1	<0.1	<0.1	<0.06	0.15	<0.006	-
Phenols	0.003	0.007	<0.001	0.001	<0.001	<0.001	0.001	0.002	-
$SO_4^=$	1394	1407	814	1496	1200	1290	1540	1410	-
Zn	<0.05	<0.05	<0.05	<0.05	<0.02	0.02	<0.05	<0.05	-
NH_3	-	0.59	0.55	-	0.317	-	-	-	-

* All concentrations given in mg/L except Ra-226, given in pCi/L
† Analytical interference due to high background Ca concentrations
** Consol waste results from previous report/1/

Both kinds of fixated LIF wastes were then subjected to the MOE Regulation 309 Leachate Extraction Procedure in the same manner as the "As Received" wastes. The analyses of the resulting leachates are listed in Table 10, together with the results of the "As Received" leachate analyses.

Conditions of the fixation tests, including the water-to-LIF waste ratios and moisture content of the fixated wastes, are detailed in Table 11. (There was insufficient CRF waste to conduct "Fixated and Dried" tests from that source).

Determination of an exact optimum amount of water to mix with the LIF wastes for easy handling was difficult to pinpoint. The weight ratios indicated in Table 11 represent the best practical estimate. Table 12 briefly summarizes handling characteristics of the products obtained after tests at various water-to-LIF waste ratios. The observations were recorded from the calorimetry tests, which afforded the best opportunity to examine the waste products in detail.

During the initial stages of the fixation procedure, it was found that most of the LIF wastes became hot while mixing with water, and steam was released from some of the mixtures. If insufficient water was added at the start of the 5 min mixing period many of the mixtures were too stiff to transfer to the curing or drying containers.

With the water-to-solid ratios used for the fixation tests (Table 11) the mixtures were all watery slurries at the start of the 5 min mixing period, but by the time they were poured into the curing or drying containers most or all of the free water had gone. This is attributed partly to chemical reaction, partly to absorption and to evaporation.

3.7 Engineering/Physical Testing of Fixated LIF Wastes

To measure the handling characteristics and suitability of fixated LIF waste for landfill, the selected LIF wastes were submitted to Civil Research Department for appropriate engineering and physical tests.

The following LIF waste-to-water ratios were recommended to Civil Research Department for fixating the wastes prior to the engineering tests:

Sample	LIF Waste to Water Ratio
D85#4	1:1
J/J86#22	1:1.2
J/J86#35	1:1.2
J/J86#41	1:1.4
J/J86#46	1:1
CRF-1	1:1.2

TABLE 11

LIF WASTE FIXATION TESTS

CONDITIONS OF FIXATION AND MOISTURE ANALYSIS OF FIXATED PRODUCT

LIF Waste Sample	Sample to Tap Water Ratio		Curing Time at 23°C in 100% Humidity Room (days)	Drying Time in Air at 24°C (days)	Moisture Content Of Fixated Sample (g H_2O/kg Sample)
	LIF Sample (g)	Tap Water (g)			
D85#4					
-FC	1 (40)	0.88(35)	7	-	386
-FD	1 (40)	0.88(35)	-	4	2
J/J86#46					
-FC	1 (40)	1 (40)	7	-	412
-FD	1 (40)	1 (40)	-	4	3
J/J86#35					
-FC	1 (40)	1.12(45)	7	-	477
-FD	1 (40)	1.12(45)	-	4	8
J/J86#22					
-FC	1 (40)	1 (40)	7	-	402
-FD	1 (40)	1 (40)	-	4	6
J/J86#41					
-FC	1 (40)	1.38(55)	7	-	526
-FD	1 (40)	1.38(55)	-	4	78
CRF-1					
-FC	1 (40)	1.38(55)	7	-	521
CRF-2					
-FC	1 (40)	1.25(50)	7	-	472

FC denotes 'Fixated and Cured' at 23°C (100% relative humidity) for 7 days.
FD denotes 'Fixated and Dried' at 24-25°C (open laboratory) for 4 days.

TABLE 12

DESCRIPTION OF SLAKED PRODUCTS OBTAINED FROM COMBINING VARIOUS RATIOS OF LIF WASTE AND WATER IN CALORIMETRY TESTS*

LIF Waste Sample	LIF: Water Ratio (Weight Basis)	Ambient & Water Temperature (°C)	Description of LIF Waste/Water Mixture After Calorimetry Test Completed
J/J86 #46	40:10	25	-Mixture of dry powder & dry set material which had to be broken up to remove from the calorimeter: a dry mixture of lumpy/powdery material.
	40:25	24.1	-Damp-to-dry mixture of powder & lumps and some damp semi-set material which had to be chipped out of calorimeter: a mixture of damp to dry powder and lumps of light to moderately set material.
	40:50	24.7	-stiff wet sandy plaster: a thin film of excess water squeezed out when material handled.
	40:65	24.7	-wet sandy plaster which separated out into a solid phase with a small supernatant aqueous layer.
	40:80	25	-watery slurry, settled out into a solid layer with a supernatant aqueous layer.
J/J86 #35	40:10	23-25	-same as #46 40:10 ratio
	40:25	"	-same as #46 40:25 ratio
	40:50	"	-same as #46 40:50 ratio
	40:65	"	-same as #46 40:65 ratio
	40:80	23.5	-same as #46 40:80 ratio
J/J86 #22	40:10	23-25	-same as #46 40:10 ratio
	40:25	"	-same as #46 40:25 ratio
	40:30	"	-most of material had taken on a moderate plaster-like set except around stirrer-Had to break material up to remove from calorimeter: a mixture of dampish moderately-set lumps
	40:50	"	-same as #46 40:50 ratio
	40:65	"	-same as #46 40:65 ratio
	40:80	"	-same as #46 40:80 ratio
J/J86 #41	40:25	24	-same as #46 40:25 ratio
	40:50	24.7	-good working plaster consistency: no excess water - smooth paste
	40:65	23.2	-same as #46 40:50 ratio
	40:80	23.5	-same as #46 40:65 ratio
CRF-1	40:15	24.5	-same as #46 40:25 ratio
	40:18	24.2	-same as #46 40:25 ratio
	40:25	24.8	-same as #22 40:30 ratio-fairly hard to chip out
	40:40	24.1	-same as #41 40:50 ratio
CRF-2	40:65	23.4	-same as #46 40:50 ratio

* The calorimetry tests afforded the best opportunity to examine the waste products in detail.

Details of the engineering test results are appended to this report (Appendix 1). A brief summary is given in Table 13.

4.0 DISCUSSION AND SUMMARY

Major chemical analysis of LIF wastes received from dry sorbent injection trials held at Lakeview TGS (December, 1985 and June/July, 1986) showed that these wastes contained CaO contents as high as 360 g/kg and 429 g/kg respectively. The highest solid waste CaO contents were found to be associated with the highest rates of sorbent limestone injection (peaking at a Ca/S ratio of 4.04). Exothemicity was found by calorimetry to be in the order of $\Delta H \approx -100$ cal/g whether limestone or slaked lime was injected; likewise bulk exothemicity tests yielded maximum internal temperatures as high as ~190°C with either sorbent. The amount (by weight) of water required to bring the "as received" waste to a flowable "wet plaster"-like consistency was in the range 1.0 to 1.2 parts water per one part waste for limestone injection wastes, and 1.4 parts water per one part of waste for slaked lime injection waste. In flow tests, the limestone injection waste exhibited higher flow than the slaked lime injection waste.

Bulk densities of the fixated wastes averaged about 1350 kg/m^3, with moisture contents (dry basis) of the limestone injection wastes in the order of 70%. The dry basis moisture content of the fixated slaked lime injection waste was higher, at about 90%. The shear strength of the fixated limestone waste was up to double that of the fixated slaked lime injection waste. (This was also true of the corresponding unconfined compressive strength.) Permeabiities of the fixated limestone injection waste were in the range 2.9×10^{-5} cm/s to 1.4×10^{-4} cm/s, ie similar to regular fly ash permeabilities. Difficulty was experienced in trying to obtain a cylindrical sample of fixated slaked lime injection waste (J/J86#41) for permeability testing (Appendix, Table III). This sample, which had a higher moisture content than the corresponding limestone injection wastes after 28 days' moist curing, tended to fall apart on release from the split mould, so that no permeability testing could be done on it. Although rigid proof is lacking, its higher moisture content may indicate a higher degree of permeability.

No trace element analysis of the LIF wastes was done, either on the "as received" or on the fixated wastes, since the presence of trace components is practically academic unless they are released, eg, by leaching. If deemed necessary to satisfy specific requirements of the MOE, however, retained samples of previous LIF wastes and also of "new" wastes to be produced in further trials to be held at Lakeview TGS in July/August, 1987, can be submitted for trace element analysis.

TABLE 13

ENGINEERING TESTS OF FIXATED & CURED LIF WASTE SAMPLES RECEIVED FROM LAKEVIEW TGS
DECEMBER 1985 AND JUNE/JULY 1986

Sample No	Description								Handling Characteristics (Average)		Fixated Material Properties (28-day cure period)				
	Date	Test No	Load (MW)	Sorbent	Injection Rate (Mg/h)	Ca/S Ratio	Flue Gas SO_2 Concn. (mg/L)	Blend of Hopper Numbers	Ratio of Water to LIF Waste (w/w)	Flow Test: Dia of Flow (mm)	Bulk Density (kg/m^3)	Moisture Content (% Dry Solids Basis)	Shear Strength kPa	Unconfined Compressive Strength kPa	Permeability (cm/s)
D85#4	Dec 11/85	5	220	limestone	12.1	3.0	842	11 (west)	1.0:1	430	1303	78.1	174	348	1.4×10^{-4}
J/J86#46	Jul 4/86	5	300	limestone	17.8	3.17	1010	6,8,14,16(East)	1.0:1	450	1319	61.4	272	544	2.9×10^{-5}
J/J86#19							1010	9,11,17,19(West)							
J/J86#34	Jul 9/86	11	220	limestone	15.2	3.76	756	6,8,14,16(East)	1.2:1	140	1390	70.0	253	506	4.4×10^{-5}
J/J86#35							756	9,11,17,19(West)							
J/J86#22	Jul 10/86	3	300	limestone	25.0	4.04	825	6,8,14,16(East)	1.2:1	420	1272	74.9	147	291	1.4×10^{-4}
J/J86#17							825	9,11,17,19(West)							
J/J86#39	Jul 14/86	4	220	slaked lime	11.0	3.53	655	6,8,14,16(East) 9,11,17,19(West)	1.4:1	75	1367	90.2	138	276	-

There was insufficient sample received from the Combustion Test Facility, 1986, to conduct engineering tests.

One limestone- and one slaked lime-injection waste was generated in the Combustion Research Facility during preliminary tests held in fall, 1987. Each was a composite waste. There was sufficient material for major chemical analysis of these wastes, but insufficient to generate a detailed evaluation in terms of the physical/engineering characteristics of the fixated wastes.

Selected samples of the "as received" and fixated LIF wastes from the Lakeview (December, 1985 and June/July, 1986) tests and also from the Combustion Research Facility (Fall, 1986) preliminary tests were subjected to the MOE Leachate Extraction Procedure (co-disposal conditions). Extract components of interest to the MOE were consistently below the leachate toxicity limits, ie, the wastes were non-hazardous. pH values remained high (about pH 12.2), corresponding to $Ca(OH)_2$ aqueous saturation. Boron, selenium and chromium, all of which tend to form oxy-anions in alkaline solution, were found to be lower in extract concentrations derived from the fixated samples compared with the corresponding extracts from the "as received" LIF wastes. Aqueous extraction under monofill conditions showed LIF wastes to be generally acceptable for backfill use.

It is emphasized that fixation is necessary primarily to improve the engineering/mechanical properties of the LIF waste for handling, landfilling, etc.

The results obtained from tests done to date show that the LIF wastes are unlikely to contain much more than 40% w/w of CaO, whereas bulk transportation of free quicklime CaO (industrial grade) is permitted on Provincial highways. This implies that dry transportation of LIF solid wastes by tanker should not pose any special problems. In principle, conditioning of the waste may be accomplished by water addition either in the station or at the disposal site. It is arguable that trucking of very large quantities (say, three times the amount of regular fly ash) of slaked, moist LIF wastes over considerable distances on public highways should be avoided, since drying out and dusting can pose a serious environmental problem. There are distinct advantages in this respect to be gained by slaking and conditioning the waste at (or close to) the disposal site. To date, the most promising conditioning equipment appears to be that supplied by Mixer Systems Inc, Pewaukee, Wisconsin, who claim/5/ to have effectively conditioned Western US high-calcium fly ash (26% CaO) for well over a year at the Riverside Station of the Northern States Power Utility, near Minneapolis, Minnesota, with nearby landfill. It is clear that developmental work by Ontario Hydro is needed to establish optimal LIF waste slaking conditions from the dual standpoint of waste handling and disposal in an environmentally safe manner. It has been recommended /6/

that Power Equipment Department and Mechanical Design Department should conjointly investigate the best equipment and modus operandi, and Chemical Research Department and Civil Research Department will provide any necessary backup services in devising and evaluating the efficacy of alternative process schemes.

Plans for the next series of LIF tests to be held at Lakeview TGS in July/August 1987 are currently being formulated. From the standpoint of waste handling and disposal, as well as improved process performance, it would be of interest to test (a) re-injection of waste into the boilers, and/or (b) sorbent injection with humidification. Re-injection would provide an opportunity for waste reduction, producing a waste with increased levels of $CaSO_4$ and less CaO, which would give a more readily handleable, more compact waste. Humidification should yield a waste with minimal residual CaO, which would greatly reduce waste handling and disposal difficulties. At this early stage, however, it appears unlikely, for practical operational reasons, that either of these options will be tried in the Lakeview LIF trials to be held in summer 1987.

It is suggested that laboratory column leaching tests could provide much-needed information to facilitate prediction of field leaching behaviour at a given disposal site. Scaled-up tests of landfill disposal should be held at a suitable site, eg, at Nanticoke TGS, for which much more geotechnical information is available compared with, say, Lakeview TGS or Lambton TGS.

5.0 RECOMMENDATIONS

1. It is recommended that care continue to be exercized in handling/disposal of LIF waste in view of its confirmed potential for exothermic reaction, with expansion, steaming and dusting.

2. Further work is recommended in the following areas:

   (i) Laboratory characterization of wastes to be generated during further LIF trials to be held at Lakeview TGS in July/August, 1987. These will include wastes derived from injection of (a) limestone and (b) slaked lime.

   (ii) Laboratory evaluation of other LIF wastes produced at the Combustion Research Facility under various operating conditions, eg Ca/S ratio, humidification, alternative sorbents and promoters, etc, as necessary.

(iii) Tests of slaking/conditioning equipment with improved control characteristics compared with the dustless unloaders currently in use eg at Lakeview TGS.

(iv) Scaled-up tests of disposal practicability (eg, at Nanticoke TGS) by placing the fresh LIF waste/water conditioned mixes in dyked-off test plots where they can be allowed to set and cure. (Laboratory column leaching tests should accompany the field testing.)

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APPENDIX

PHYSICAL/ENGINEERING PROPERTIES OF FIXATED LIF WASTES - 1986 PROGRAM

Section File, KR252

ontario hydro
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To Dr. O.A. Kupcis
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PHYSICAL PROPERTIES OF LIMESTONE INJECTION FEED BY-PRODUCTS FROM 1986 PILOT TEST PROGRAMS

C.B.H. Cragg

INTRODUCTION

SO_2 and NO_x can be removed from the stack gases of coal fired generating stations by directly injecting finely ground limestone into the plant boilers. The by-product of this Limestone Injection Feed (LIF) process contains roughly equal parts of fly ash, gypsum and free lime which is collected dry on the stack precipitators. For preliminary assessment, LIF by-products obtained from a US utility were tested for physical behaviour in 1985/1/. In 1986, LIF by-products were created in Ontario Hydro's Lakeview GS and Chemical Research's Combustion Research Facility (CRF). Results of physical property tests on these (1986) materials are summarized in this report. Similarities and differences between the 1986 and 1985 material properties are discussed.

TESTS PERFORMED

In order to handle the LIF by-product, sufficient water must be added to create a flowable slurry. Slump tests and flow tests were performed on the slurry immediately after mixing to determine pumpability relative to concrete or K-Krete.

Cylindrical samples of the slurry were formed in molds and allowed to harden and cure for various time periods. The shear strength (by confined, undrained compressive strength test) and permeability (by triaxial test) were determined for samples after 7, 15 or 28 days of curing. Effects of curing in environments with high and low relative humidity were examined. The bulk density and water content (dry weight basis) of each sample was measured at the time of strength or permeability testing. The number of tests performed on the CRF material was limited by the small amount of material supplied.

job	file	date	report no.
31-204-490	843.2	April 14, 1987	S87-11-K

TEST MATERIALS AND SAMPLE PREPARATION

Table I shows the 5 samples of LIF from test burns at Lakeview GS and 1 sample from test burns at the Combustion Research Facility (CRF) and the amount of mix water used in making the physical property test samples. The LIF samples and mix water proportions were submitted by Chemical Research. It is understood that these water contents were found (by Chemical Research) to be necessary to avoid setting of the mixture in the mixing apparatus.

The water and LIF were mixed in a Hobart mixer (about 3 minutes) to form a uniform consistency slurry. Cylindrical samples, 50 mm diameter by 100 mm long, were formed by pouring the slurry into split molds. Some of these samples were cured in a 100% relative humidity curing chamber and some were cured at ambient relative humidity (20% RH +/-) in December 1986. Physical properties of the samples were measured after 7, 15 or 28 days of curing.

TEST RESULTS

Table II shows that the diameter of the pancake formed in the flow tests ranged from 75 mm to 450 mm with most of the samples exhibiting flows over 400 mm. By comparison, the 1985 samples generally exhibited less flow, 79 mm to 168 mm. The smaller flows of 1985 LIF materials may be due to the lower water proportions in the 1985 mixes (0.75 to 0.81 water: 1.0 LIF) possibly combined with coarser grain sizes of the 1985 materials. Unfortunately, grain size analyses were not done for the 1985 test materials. Figure 1 and Appendix A give grain size data for the 1986 test materials.

From Table III, it may be seen that the LIF samples had bulk densities ranging from 1213 kg/m^3 to 1406 kg/m^3 with water contents between 60.7% and 91.6% after 15 to 28 days of moist curing. Dry curing for 7 to 15 days produced bulk densities (see Table IV) ranging from 761 kg/m^3 to 865 kg/m^3 with water contents in the 1.0 to 2.4% range. On average, the moist cured 1986 samples are less dense and contain more water than the 1985 samples/1/. The relative averaged figures are: for bulk density 1350 kg/m^3 (1986) versus 1560 kg/m^3 (1985) and for water content 73% +/- (1986) versus 58% (1985).

For sizing landfills, a value of 674 kg of dry LIF product per cubic meter may be used. This value is obtained from the average bulk (moist cured) density, reduced by the average moisture content and reduced by a further 15% for water of hydration bound to the LIF, according to atomic weight balances performed by Chemical Research.

The shear strength and strain at failure for the moist and dry cured samples are shown in Tables III and IV respectively. In general, shear strength for the moist cured samples from the Lakeview GS burns doubled from around 100 kPa (+/- 50 kPa) at age 15 days to around 200 kPa (+/- 70 kPa) at age 28 days.

The moist cured CRF sample, with a 28 day shear strength of 500 kPa, departed significantly from this general trend. The CRF sample was also

more brittle with a failure strain of about 1% versus 6% to 16% for the Lakeview samples.

When dry cured, the Lakeview samples showed a shear strength gain of only 10% between 7 and 15 days of curing. Seven day shear strengths were about 205 kPa (+/- 25 kPa) and fifteen day shear strengths were about 230 kPa (+/- 30 kPa). Strain at failure ranged from 4% to 18%, similar to the moist cured results. The dry cured samples were initially stronger than the moist cured samples but gained strength at a much lower rate. While the dry cured 1986 samples were initially as strong as the 1985 samples (Figure 2), the long term strength of all samples (except the CRF sample) was found to be much lower than the material tested in 1985. These lower shear strengths are consistent with the lower densities of the 1986 samples.

Permeabilities of the 1986 samples ranged from 2.9×10^{-5} cm/sec to 1.4×10^{-4} cm/sec (Table V). These values are similar to fly ash permeabilities but much higher than the 10^{-6} to 10^{-7} cm/sec found for 1985 LIF tests. This difference is again consistent with the lower density, or conversely higher void content, of the 1986 samples compared to the 1985 samples.

SUMMARY

Physical property measurements were performed on LIF by-products obtained from 1986 test burns at Lakeview TGS and the Research CRF. Test specimens were prepared with more mix water than in 1985 and were found to have lower bulk densities, higher water contents (moist cure), lower shear strengths and higher permeabilities than the 1985 specimens. Dry curing produced higher initial strength but a lower rate of strength gain with time, compared to moist curing.

Due to the changes observed between the 1985 and 1986 results, it is recommended that LIF by-products from the finalized production process be tested to provide physical properties for design and environmental assessment of the LIF disposal pile. These tests should also allow for

tests on material cured for periods up to 4 months to determine long term properties.

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DISTRIBUTION

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TABLE I

Materials Used in 1986 LIF Tests

LIF Material Code	Water Proportion in Mixture* (water: LIF, by weight)
D85#4	1.0:1
J/J 86 #22	1.2:1
J/J 86 #35	1.2:1
J/J 86 #41	..4:1
J/J 86 #46	1.0:1
CRF-1	1.2:1

*Toronto tap water

TABLE II

Flow Properties of 1986 LIF By-Products

LIF Material Code	Average Diameter of Flow (mm)	Average Height of Pancake (mm)
D85 #4	430	5
J/J 86 #22	420	10
J/J 86 #35	140	100
J/J 86 #41	75	150
J/J 86 #46	450	5
CRF-1	insufficient material for testing	

TABLE III

Shear Strength* of Moist Cured 1986 LIF By-Products

Specimen	15 DAYS Bulk Density (kg/m^3)	15 DAYS Water Content (%)	15 DAYS Shear Strength (kPa)	15 DAYS Strain (%)	28 DAYS Bulk Density (kg/m^3)	28 DAYS M/C (%)	28 DAYS Shear Strength (kPa)	28 DAYS Strain (%)
D85#4								
S-1	1365	75.8	85	14.7	1315	79.1	170	9.8
S-2	1348	78.0	86	13.7	1292	77.1	179	9.8
AVERAGE	1356	76.9	85	14.2	1303	78.1	174	9.8
J/J 86 #22								
S-1	1286	77.6	67	10.7	1261	74.0	147	11.7
S-2	1303	79.3	60	13.7	1283	75.8	148	13.0
AVERAGE	1295	78.4	63	12.2	1272	74.9	147	12.4
J/J 86 #35								
S-1	1386	73.7	125	19.9	1395	70.2	251	10.8
S-2	1406	74.0	110	12.9	1386	69.8	255	7.8
AVERAGE	1396	73.8	117	16.4	1390	70.0	253	9.3
J/J 86 #41								
S-1					1366	88.8	139	8.1
S-2					1368	91.6	138	7.1
AVERAGE					1367	90.2	138	7.6
J/J 86 #46								
S-1	1340	64.2	153	9.8	1312	62.1	263	6.8
S-2	1370	63.1	153	9.9	1326	60.7	282	4.9
AVERAGE	1355	63.6	153	9.8	1319	61.4	272	5.9
CRF-1								
S-1					1213	67.0	516	1.3

*Quick undrained (Q/U or U/U) shear test, confining pressure = 100 kPa

NOTES

1. J/J 86 #41 cylindrical specimens fell apart when molds stripped for 15 day moist cure Q/U tests.
2. CRF-1 sample size permitted only one cylinder to be made
3. Bulk densities should be regarded with some caution due to inconsistent distributior of voids among specimens.
4. A wide range of percent strain existed for specimens of the same conditions.
5. Q/U testing of dry specimens was characterized by a constant fluctuation of stress dial readings as maximum stress approached.

TABLE IV

Shear Strength* of Dry Cured 1986 LIF By-Products

Specimen	7 DAYS Bulk Density (kg/m^3)	7 DAYS Water Content (%)	7 DAYS Shear Strength (kPa)	7 DAYS Strain (%)	15 DAYS Bulk Degsity (kg/m^3)	15 DAYS M/C (%)	15 DAYS Shear Strength (kPa)	15 DAYS Strain (%)
D85#4								
S-1	865	1.0	238	3.9	828	1.7	257	1.0
S-2	812	1.2	216	4.9	825	1.6	231	6.8
AVERAGE	839	1.1	227	4.4	826	1.7	244	3.9
J/J 86 #22								
S-1	783	1.3	191	7.8	821	2.4	227	5.9
S-2	798	1.4	190	8.8	825	2.4	197	12.9
AVERAGE	791	1.3	190	8.3	823	2.4	212	9.4
J/J 86 #35								
S-1	761	1.3	165	19.8	817	1.9	197	8.9
S-2	786	1.6	187	16.3	824	2.1	196	10.9
AVERAGE	773	1.4	176	18.0	820	2.0	196	9.9
J/J 86 #41								
S-1	765	1.9	201	16.3	801	2.4	236	2.1
S-2	795	2.1	204	7.1	813	2.3	222	13.1
AVERAGE	780	2.0	202	11.7	807	2.4	229	7.6
J/J 86 #46								
S-1	805	1.9	215	2.9	823	1.9	257	8.7
S-2	817	1.7	249	3.9	819	2.0	260	8.8
AVERAGE	811	1.8	232	3.4	821	1.9	258	8.7

*Quick undrained (Q/U or U/U) shear test, confining pressure = 100 kPa

NOTES

1. J/J 86 #41 cylindrical specimens fell apart when molds stripped for 15 day moist cure Q/U tests.
2. CRF-1 sample size permitted only one cylinder to be made
3. Bulk densities should be regarded with some caution due to inconsistent distributior of voids amony specimens.
4. A wide range of percent strain existed for specimens of the same conditions.
5. Q/U testing of dry specimens was characterized by a constant fluctuation of stress dial readings as maximum stress approached.

TABLE V

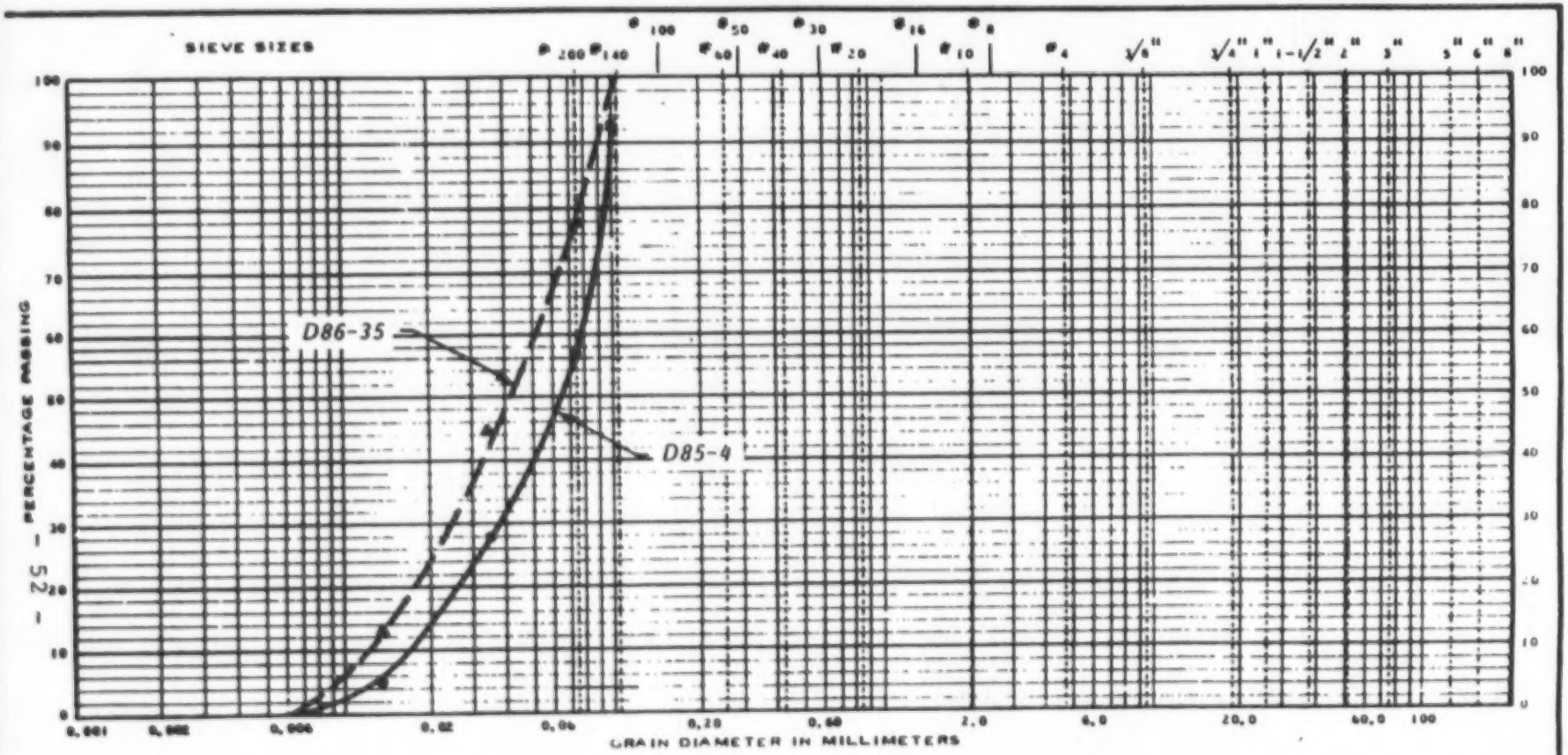
Permeability Tests on 1986 LIF By-Products*

LIF Material Code	Bulk Density (kg/m^3)	Permeability (cm/sec)
D85 #4	1322	1.4×10^{-4}
J/J 86 #22	1277	1.4×10^{-4}
J/J 86 #35	1454	4.4×10^{-5}
J/J 86 #46	1386	2.9×10^{-5}

*Test Conditions: confining pressure 70 psi
line pressure 50 psi
back pressure 40 psi
head 10 psi

(tests performed by Peto MacCallum Ltd, Dec 1986)

MECHANICAL ANALYSIS



CLAY	TO SILT	SAND			GRAVEL		COBBLES
		FINE	MEDIUM	COARSE	FINE	COARSE	

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new 80-11

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FIGURE 1

INTERPRETED SIZE DISTRIBUTION OF
LIF REACTION PRODUCTS (1986 TESTS)

87-146

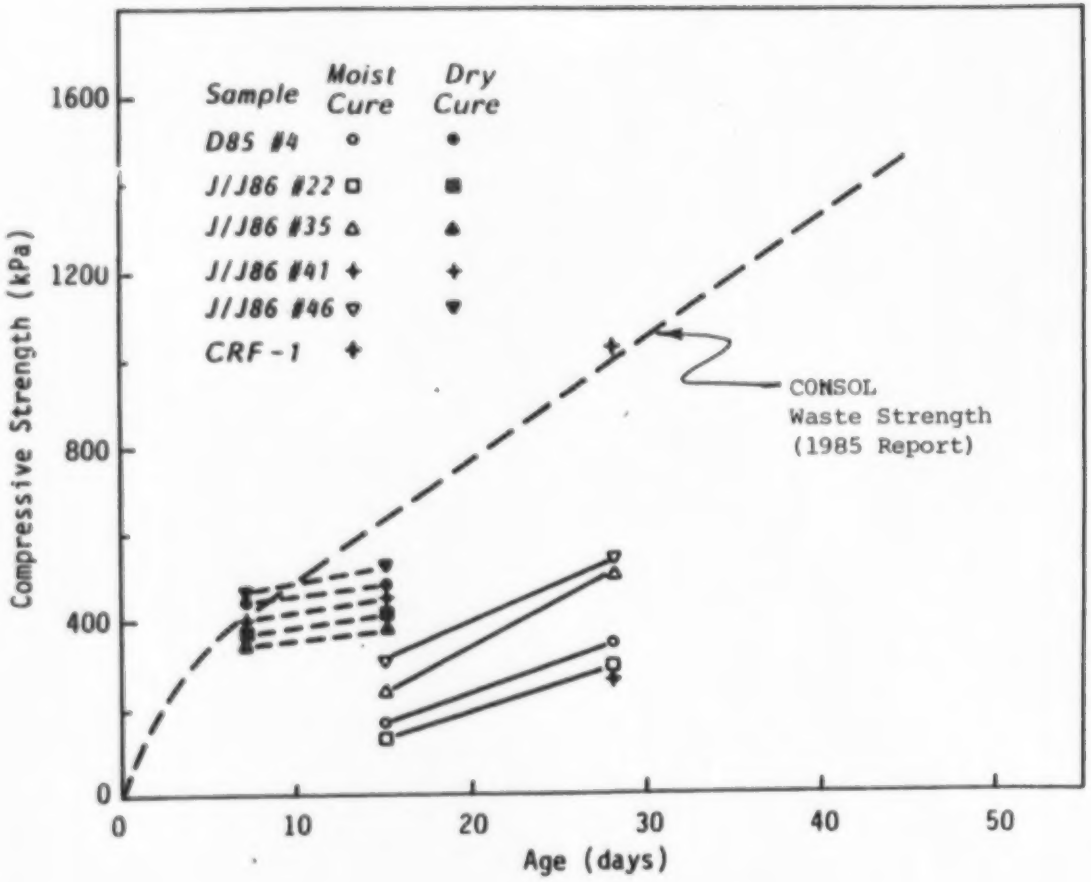

FIGURE 2

STRENGTH GAIN WITH AGE OF 1986 LIF BY PRODUCTS - MOIST AND DRY CURED

DISTRIBUTION

Dr. W.R. Effer	Design & Dev-Generation, H10G01
Mr. C.W. Dawson	Design & Dev-Generation, H10D01
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